PN AAQ 970
ISN: 36481

CENTER FOR DEVELOPMENT TECHNOLOGY

WASHINGTON UNIVERSITY
SAINT LOUIS, MISSOURI 63130

Report Number
THA/CDT 80/2

February, 1980

APPROPRIATE TECHNOLOGY FOR BUILDING MATERIALS FROM AGRO-WASTES AND NATURAL FIBERS

CHARLES G. KICK, III

This study was taken from a thesis prepared for the Master of Science degree in Technology and Human Affairs. It was partially supported by U.S. AID contract No. AID/DSAN-C-0061 and by Washington University under the College Work-Study Program. The views expressed in this report are those of the author and do not necessarily represent those of the Department of Technology and Human Affairs, the Center for Development Technology, Washington University, or the U.S. Agency for International Development.

ABSTRACT

This report presents a state-of-the-art review and analysis of appropriate, capital-saving, technologies which might be used by developing country villagers, cooperatives, or farmers for the manufacture of materials for building, etc. from agro-wastes and natural fibers. The needs of developing countries are reviewed, along with the needs for further R&D on such materials and technologies. The capabilities of institutions around the world to further the applications of these technologies are discussed, and mechanisms and initiatives are suggested for U.S. involvement through international assistance and cooperation.

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APPROPRIATE TECHNOLOGY FOR BUILDING MATERIALS FROM AGRO-WASTES AND NATURAL FIBERS

1. INTRODUCTION

The Earth's population and societies are such that they depend directly on a continuing supply of resources to provide the means of maintaining the present civilization. More importantly, this resource stream has to increase rapidly because of three factors. One, the world's population is growing rapidly; it is projected (1, 2)* to increase by between fifty and one hundred percent in the last quarter of this century. Two, already high standards of living in the industrialized countries should continue. And finally, over sixty percent of the world's population is located in developing countries (1); these people are pressing for growth in their standard of living that will allow them to catch up with the industrialized countries. Clearly, this exponential process cannot go on forever because the Earth is of finite size. Its resource stocks which cannot be renewed are also finite.

*The numbers in parentheses in the text indicate references in the bibliography.

It is obvious that we have a major problem facing us if we are to give consideration to the resource needs of future generations and, perhaps as important, the resource needs of the impoverished current residents of the "Third World." (1) This problem is complicated by the uneven distribution of many natural resources; nations do not always have the equal or direct access to resources their societies feel they need. Recycling can extend our resource stocks, but doing this also requires resources, especially energy.

Most of the resources not consumed for food or energy uses are consumed in the production of structures, vehicles, and transportation/communication infrastructure. (3) These resources are as exhaustible as our hydrocarbon energy resources, at least in the sense that the costs of supply (extraction, transportation) may increase to the point where consumption is limited or halted. (3, 4) In some areas this is especially true with even such "common" resources as sand and gravel (4), and in other areas with metals. (2)

This situation has resulted in a growing interest in the use of renewable resources to meet both energy and non-energy resource requirements. In addition to the popular forms of renewable resources - solar and wind energy - there are the perhaps less glamorous biomass resources (plants and animals) which have provided the world's population with food, clothing, energy, and shelter since the dawn of man. Many countries are conducting research into the improvement, diversification, and increase of their biomass resources. (3, 5-12) Some of the developing countries which comprise the "Third World," where much of the increased demand for resources will come from, have to contend with a lack of research and development capacity (12), a lack which may seriously impede the supply of adequate resources to meet their peoples' felt needs.

In the early periods in the development of what are now the industrialized countries, considerable use was made of biomass resources. The people of those times found the plants and animals of their environment to be good sources of materials because they could be exploited with relatively simple and inexpensive tools and machines. Such exploitation provided considerable employment for the value of goods produced. (3, 11, 13) As more compact, less expensive, energy sources were discovered and developed, mineral and hydrocarbon resources became exploitable for less than the costs of exploiting many biomass resources. Using modern scientific capabilities, the developing countries are trying to develop their biomass resources - resources which, because of the tropical climates of most developing countries, are often more diverse than those that were available in industrialized countries. (12) Yet as noted, many of these countries are short of the capacity to do this.

The most versatile biomass resource is timber. (3, 4, 5, 14) In addition to its traditional uses for shelter and energy, it can provide many of the industrial materials now provided from hydrocarbon resources. (14, 15) However, in terms of improving the lives of the developing countries' poor, timber production and exploitation may not by itself provide the levels of employment possible with other biomass resources. (16) Completing the exploitation of agricultural biomass by utilizing all parts of the plants which are now grown primarily for food or fabric may offer more immediate benefits to larger numbers of people. The residues produced while satisfying two human needs, food and clothing, which are now used for low value-added uses (like fodder, farm energy, soil amendment, or short lived building materials) can be used to meet more durable building materials and other material needs.

Building materials produced from agricultural wastes and natural fibers at scales available to and usable by rural developing country people are not an absolute necessity for some of these people because they frequently have ready access to their traditional, short-lived, materials. As populations increase however, such traditional resources are frequently overexploited, rendering them expensive or locally extinct. Also, agricultural production provides only seasonal employment for many of these people, which can add to migration to urban areas (1) and increase demands there for housing materials. The production of agricultural waste and natural fiber materials which are capable of meeting markets more demanding than rural ones may help to meet the material needs for the estimated 35 million housing units needed in the world each year, a large portion of which are needed in the urban or urbanizing areas of developing countries (17), as well as provide the agricultural sector with a larger value-added output, meaning more employment for these rural dwellers and possibly slower rural-urban migration. Meeting these needs is a major goal of some countries' development plans. (18)

1.1 OBJECTIVES OF THESIS

1.1.1 Thesis Statement

A major objective of this thesis is to define initiatives in appropriate, capital-saving, technology* for non-food and non-fuel

*Defined in Section 1.2.3.1.

products from agricultural wastes and natural fibers which might be supported by the United States in connection with U.S. programs of international scientific and technological assistance and cooperation. As a part of this process of initiative definition, the needs and limiting conditions of developing countries will be discussed, and the current state-of-the-art of those technologies which relate to the initiatives will be reviewed and analyzed. In addition, the potential contributions of U.S. universities, research institutes, private industry, and voluntary organizations, along with mechanisms for coupling these resources to developing country (DC) institutions in order to implement promising initiatives will be presented and discussed.

1.1.2 Thesis Origin

This thesis is an offshoot of a larger study, Appropriate Technology for Renewable Resource Utilization (ATRRU or Principal Study) (19), undertaken by Washington University's Center for Development Technology (CDT) in collaboration with VITA, Volunteers In Technical Assistance, under a contract with the U.S. Agency for International Development (AID) as part of U.S. preparations for the August, 1979, United Nations Conference on Science and Technology for Development (UNCSTD). The ATRRU study focused on five principal topic areas: wind energy, improved cookstoves, solar drying, food products from rice bran and other agricultural by-products and wastes, and non-food/fuel products and materials from agricultural and timber wastes and natural fibers. This thesis constitutes an expanded version of the latter topic area of the Principal Study.

The products reviewed in this thesis can be made from agricultural residues and natural fibers commonly found in many developing countries: cement and other binders from rice hulls and cassava; fillers, blocks, and panels from rice, coconut, sugar, and banana wastes; and paper from many such residues. All of these materials can be produced with technologies that might be afforded by individual farmers, or, at least, rural cooperatives. The author's interest in these technologies and products stems from his architectural background and from his involvement in construction and development planning work in a small developing country (Fiji) which is heavily dependent upon imports for many of its building materials, especially steel and other metals, and for the energy to produce and transport materials made in large quantitites at one place in the country. (20) It is hoped that this thesis will be a furthering of work in the areas of low-cost housing and building materials for developing countries based on renewable resources.

1.2 BACKGROUND AND LIMITATIONS OF THIS STUDY

1.2.1 UNCSTD and U.S. Preparations

One of the major activities of the United Nations (UN) is to hold or support conferences on matters of contemporary worldwide or regional importance or concern. Recent conferences have included topics such as the law of the sea and population. This thread was followed in August, 1979, when the UN convened a conference on Science and Technology for Development.

In 1963, the UN General Assembly called for* a Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas which was held in Geneva the same year. While this

*General Assembly Resolution 1944 (XVIII) (1963).

early conference was initially conceived:

> "...as a means of exploring the application of recent advances in science and technology, the Conference found itself confronted by the much vaster and more fundamental problem of ensuring that science and technology ... should make their necessary contribution to development." (21)

By the early 1970s, though, the effect of that Conference was being questioned in the world science and technology (S&T) community, and thoughts turned to the convening of a new conference (22).

In preparation for this new conference, UNCSTD, in 1979, each nation intending to participate in the conference was asked to prepare a country paper on the current state of S&T applied to development within that country, and "promote discussions between officials responsible for economic, sectorial, social and scientific and technical planning and decision making." (22) These country papers formed the basis for regional reports "drawn up with the assistance of interregional expert groups..." (22) The developed countries were also asked to outline their potential contributions to the strengthening of the S&T capabilities of the DCs (developing countries).

The Secretary-General of the Conference, Joao da Costa, called for the most extensive participation possible, stressing that such participation should include scientific and technical communities as well as official. Da Costa noted that such preparation can be thought of as an ascending process which "should lead to a progressive formulation of analysis and proposals regarding the specific points about which concern is felt at the national level, and then at the regional, inter-regional and global levels." (23) Thus, this thesis is a small part of a nationwide and worldwide effort to illuminate and communicate the uses of science and technology for development.

In the United States, the Department of State has had the responsibility for preparing the official U.S. paper for UNCSTD (24), and will be a major focal point for continuing U.S. efforts towards science and technology for development after the Conference. In preparing the U.S. paper, State and AID received assistance from the National Research Council (NAS) (25, 26), the National Science Foundation, and from institutions/organizations like Washington University's Center for Development Technology (CDT) (27) and the Fund for Multi-Management Education (FMME). Additionally, a series of 30 workshops was held during 1978 to elicit more background information and opinions. (27)

Aided by the studies and reports mentioned above, the U.S. Country Paper for UNCSTD was prepared. The preparatory work and the paper were the responsibility of Ambassador Jean Wilkowski, the State Department Coordinator for U.S. UNCSTD preparations. Concurrently, State held the year-long series of 30 workshops in cooperation with business, labor (AFL-CIO), and educational institutions so that the U.S. paper would represent a broad cross-section of U.S. interests and points of view.

The U.S. paper is a very general statement of: United States' S&T experiences and the role these have played in our country's development; U.S. contributions to development over the past thirty years; and the role the U.S. believes appropriate for international institutions in this area. The paper also sets the tone for steps that the U.S. could take in the future. Flexibility, within the U.S. goals for the Conference, is the emphasis of the U.S. paper. The U.S. goals for UNCSTD "are offered not to exclude any specific priorities, but to comprise overarching themes that can accomodate and do justice to them all."

First: "... meeting the basic human needs of over one billion people who live in conditions of abject poverty."

Second: "... advancing the economic growth of the developing countries ..."

Third: "... to deal more effectively with global pressures on food and water, energy sources, raw materials, population growth, and the environment." (24)

By aiding DCs in the development of indigenous capacities for research into and development of light-capital* technologies for producing building and other materials from agricultural residues and natural fibers, the U.S. would also be helping those countries to meet their housing needs, one of the three elementary needs of human existence (i.e.: food, clothing, and shelter). Such aid would also assist DCs in the lowering of the rates of increase in demand for non-renewable resources and in the development of their economy through rural industrialization, through increases in their capacities to add value to products from the agricultural sector (the sector in which much of the DC population is involved), and, with product diversification, through insulation from commodity price fluctuations. Thus, such U.S. aid would meet all of the U.S. goals for UNCSTD.

1.2.2 Data Gathering

Data gathering activities for this thesis included reviews of appropriate technology and science and technology literature, as well as S&T policy, renewable resource, and international development

*See Section 1.2.3.1.

literature. Insights into common problems in the field of appropriate technology for renewable resource utilization were gained through attendance at the first (Wind Energy) and last (Solar Drying) VITA-CDT Panels and the staff meetings held in conjunction with the Principal Study. Two of the agriculturalists on the Solar Drying Panel (Van Fossen and Esmay*) discussed agro-waste materials research, and reinforced the thought that this area has been receiving little attention.

Additionally, a limited number of responses to the ATRRU mailings and inquiries were received which were somewhat relevant to this area. Of more importance were the documents received by the Principal Investigator of the ATRRU study, Dr. Robert P. Morgan, from the UNIDO Forum on Appropriate Industrial Technology, the Winrock International Workshop on Appropriate Technology, and the Segundo Simposio Internacional de Ingeniería: Technologia Apropriada Para Paises Sub-Desarrollados, which were held in November, 1978, December, 1978, and February, 1979, respectively.

In January, 1979, the author spent three days at VITA headquarters reviewing their library's holdings and some of the request files related to this area. This review provided many insights into the desires and needs of developing country individuals in the areas of housing, building materials, construction, residue utilization, and industrialization.

1.2.3 Definition of Key Terms

1.2.3.1 Appropriate Technology

The question arises as to whether industrialization in DCs requires the availability of special technology because the economic conditions

*Professors at Iowa State University and Michigan State University, respectively.

in DCs differ in many respects from those of the industrialized nations. (128) Relative to the industrialized nations, DCs usually have large ratios of unskilled to skilled labor, and the mix of labor skills within the skilled labor forces is skewed: some DCs have larger proportions of general-skill craftsmen and lower proportions of highly specialized technicians. Most DCs also have low rates of capital formation, and can be characterized as capital-poor in comparison with the developed countries. These conditions have led many to espouse the need to develop and use labor-intensive and/or capital-saving technologies in DCs. Such technologies are sometimes called "appropriate technologies," but this term can be misleading.

The term "appropriate technology" describes a concept, not a technology, and cannot be used in reference to a specific technology separated from its environment. The concept of appropriate technology has grown out of the problems encountered in transferring technology from one economic and social environment to another. The problems included differing capital and labor costs and availabilities, raw materials qualities, market facilities, and resultant social and economic dualism. (29) The concept, simply stated, is that the design of all technologies should be a reflection of the economic and social conditions prevailing at their point of <u>use</u>. (30)

While the definitions of appropriate technology, or AT as it is commonly called, are numerous and varied, the above definition is found by this writer to be the most succinct. The definition adapted by a group of AT practitioners who participated in the Winrock International Workshop on Appropriate Technology to elucidate AT inputs to the United States' UNCSTD preparations (and which was based upon the definition drafted by a UNEP expert group in 1975 and also adopted by the NSF Workshop on Appropriate Technology) fits this mold:

> "Appropriate Technology does not offer an absolute prescription but rather a process of choosing from among a broad range of options. The AT approach seeks to optimize solutions, wherever possible, through reliance on problem-solving capabilities of local people as well as a sensitivity to environmental and cultural impacts.
>
> In the process of choosing an appropriate technology, economic priorities include: maintenance of balance of material, labor, and capital supply; availability to the widest range of people; utilization of local materials; minimization of unemployment; gains for both producer and consumer. Environmental priorities include: renewable energy resources, natural resource conservation, recycling, replenishable raw materials, minimal pollutants, waste minimization, harmony with nature. Social priorities include: enhanced quality of life, creative work, elimination of alienation, maximum participation in decision-making, and respect for cultural values and practices.
>
> Characteristics of Appropriate Technology include:
>
> - Can be simple, intermediate, or high technology.
> - Choice based on dialogue and mutual respect between those who plan, produce, consume, and are affected by technologies chosen.
> - Relates to existing skills or those acquirable by training.
> - Tends to distribute political and economic power more equitably.
> - Efficient use of all resources and maintenance of low total-life costs.
> - Understandable by, and accessible to, the end users." (31)

However, in the international development arena, with its focus on reducing economic dualism and increasing production, the above definition's seemingly equal-value characteristics can assume a sort of hierarchy, as they do in the definition given in the draft report of the Technical/Official Level Meeting to the Ministerial Level Meeting of the International Forum on Appropriate Industrial Technology sponsored by the United Nations Industrial Development Organization (UNIDO). (32) The last three of the characteristics mentioned above seem to assume a lower priority than the first three:

> "... there [is] a need for reorientation in industrial strategy in most developing countries in order to extend the benefits of industrialization to all sections of the population, particularly poorer communities resident in rural areas, while sustaining overall growth. The degree of reorientation, the strategy to achieve it, and the choice of industries would vary with specific country situations, factor endowments and development objectives. The use of appropriate industrial technology [is] considered an essential element in any reorientation of industrial strategies and programs.
>
> The concept of appropriate technology was viewed as being the technology or technologies contributing most to economic, social and environmental objectives, bearing in mind the resource endowments and the conditions of application in each country. Appropriate technology was stressed as being a dynamic concept which must be responsive to changing conditions in each economy.
>
> While the concept is generally applicable and in some cases implies modern and large-scale technologies, it was felt that additional emphasis should be laid on small-scale, low-cost and relatively simple technologies that could be used by and for the benefit of the rural poor." (32)

Within and around the field of appropriate technology are terms such as "intermediate," "low-cost," "traditional," or "light-capital." The following examples given by Nicolas Jequier in his book Appropriate Technology: Problems and Promises (33) highlight the differences between these terms:

> "The ox-plough, introduced in several tropical African countries by the agricultural extension services, religious organisations and rural development specialists, is a good example of an intermediate technology. It stands, so to speak, half way between the traditional hand-operated hoe and the modern diesel tractor. Intermediateness is of course relative: in the societies of the Middle East and

> Asia which have known and used the ox-drawn plough for thousands of years such a technology can be called traditional, and the intermediate level of technology would more adequately be represented by the small two-wheel tractors of the type developed by the International Rice Research Institute in the Philippines or by the industrial cooperatives of Sri Lanka. In the tropical African societies which do not have any tradition of livestock breeding and which still use very simple implements, the ox-drawn plough is a major innovation, and from a technological point of view, it represents a big step forward." (p. 17)
>
> "The definition of what constitutes a low-cost technology is at first sight relatively simple. The ten dollar rural latrine developed by the Planning Research and Action Institute in India is quite clearly immensely less expensive than the modern flush toilet, and the water filtration system developed in Thailand, and which uses coconut or rice husks as the filtering media, is so inexpensive that it can be considered for all practical purposes as a zero-cost technology: supplying a family with pure water for one month costs around $0.20. However, as soon as one goes beyond the simple homeliving 'self-help' technology, cost calculations can become extremely complex, and it is often very difficult to determine whether a new manufacturing technology for instance is cheaper than the one it replaces or supplements.
>
> The small-scale sugar plants developed in India, and which now account for more than 20 percent of the country's production, are a good case in point. The average investment per ton of output is two and a half times smaller than in the large modern plants, and the investment per worker nine times lower [light-capital]. Differences in production costs however are much smaller (less than 20 percent), and the present balance in favour of the small-scale technology could easily be tilted." (p. 81)

This last idea -- light-capital technology -- is an extension of the low-cost idea. Its major proponent in the U.S. Congress, Representative Clarence Long of Maryland, now refers to it as "capital-saving" in juxtaposition with current industrialized nations' labour-saving technologies. Several related amendments have been offered by Representative Long which have been included in recent legislation, including one in P.L. 95-105 which required that the U.S. place "important emphasis" on light-capital technologies in preparing for UNCSTD. (27)

Timmer, et al., in The Choice of Technology in Development Countries (Some Cautionary Tales) (34), point out that development policies pursued from the 1950s to the early 1970s, while fairly successful in increasing GNP, failed in absorbing unemployment and underemployment and bettering the lot of the poor in DCs. Those policies seemingly compelled the preference of advanced country, capital-intensive technology models. Timmer, et al., show why less capital- and more labor-intensive technologies may be a part of the answer to these earlier failings. A major point made in the book is that as most DC capital budgets are limited, the technologies implemented should be designed to maximize (e.g., ration or save) the use of that capital for productive uses. Such policy is possible if sufficient capital saving technologies are available.

This whole question of scale in the building materials industry is relative. To quote the building materials industry monograph published by UNIDO in 1969, "Few building materials are manufactured on a large scale; many are produced efficiently on a relatively small scale. The industry is usually characterized by a large number of small producers." (35)

While the technologies reviewed or suggested for R&D in this report are basically those for small-scale rural use in the building materials industry, the appropriate technology may not necessarily be the smallest technology. Some wastes, like sugarcane bagasse and rice hulls from large mills, are deposited centrally in large quantities; to make use of these wastes a correspondingly large facility is required. Otherwise most of the waste will go unused.

> "It has never been claimed that small scale is automatically better than large. The intention is that these rural industries will develop into larger enterprises as the economic and social conditions of the area change -- in particular that they show growth in step with agricultural development. The numbers of people employed in them will vary from place to place according to a number of factors including the supply of raw materials and closeness of large industrial centers, but particularly to the ability of local agriculture to support them." (36)

1.2.3.2 Renewable Resources

Although the term renewable resources is somewhat self-explanatory, the following definition is given. Renewable natural resources are distinguished from non-renewable resources by the following characteristics: they grow; our total eventual consumption is not limited by the supply at any given point in time because of this growth (although our consumption at any given point in time cannot long exceed such growth, lest we destroy the stocks essential for continued growth); and to a substantial degree the quantity and quality of this growth is in man's hands. This is as true of solar energy in that its "growth," or flow, is relatively constant and renewed every instant, as it is with plants and animals. The concept of harvesting solar energy is not a new one, although the terminology is. Men have been harnessing wind and water power for centuries; farmers and sawyers have even longer been harvesting solar energy in the form of crops, livestock, or trees.

In industry, renewable resources have been a reliable source of materials since history began. Crop residues and wood have long been used as building materials or fuel. Animal and plant fibers were the original materials for clothing and textiles and, in spite of the rapid growth and widespread use of synthetics, are still extensively used. Additionally, about 95 percent of the total polymers produced from petrochemicals can be produced from wood (37), although until recent petroleum price hikes, this has usually been uneconomical.

While data regarding raw materials usage on a worldwide scale are not available, an indication of the relative importance of renewable resources to non-renewable ones in the U.S. is shown in Figure 1.1. When one considers that energy materials - coal, petroleum, etc. - account for 41.2 percent of all materials consumed in our society, and that only one percent (15) of those energy materials are used for synthetic polymers and chemicals, renewable resources account for almost an eighth* of all non-energy raw materials. Those proportions may be different in developing countries, especially those with little concrete construction, etc. DCs conceivably use much larger proportions of renewable materials.

1.2.3.3 Agricultural Wastes

In this thesis the terms agricultural wastes and agricultural residues will be used interchangeably to mean the material that is left in the field or processing facility from agricultural materials grown primarily for food. These include, for example, rice and other cereal husks and straws, cornstalks and corncobs, sugarcane bagasse, and animal wastes and by-products. Although both wastes and residues mean essentially the same thing, the term wastes is felt by some to have negative connotations. (38)

---

*$6.6 \div [100 - (41.2 \times .99)]$. The percentage of raw materials supplied by renewable resources (6.6) is used without change from Figure 1.1: Little of the U.S.'s energy comes from renewable resources - 1 percent or less - and some renewable resources appear to have not been included in the Figure, such as the oat hulls, etc. used to produce furfural.

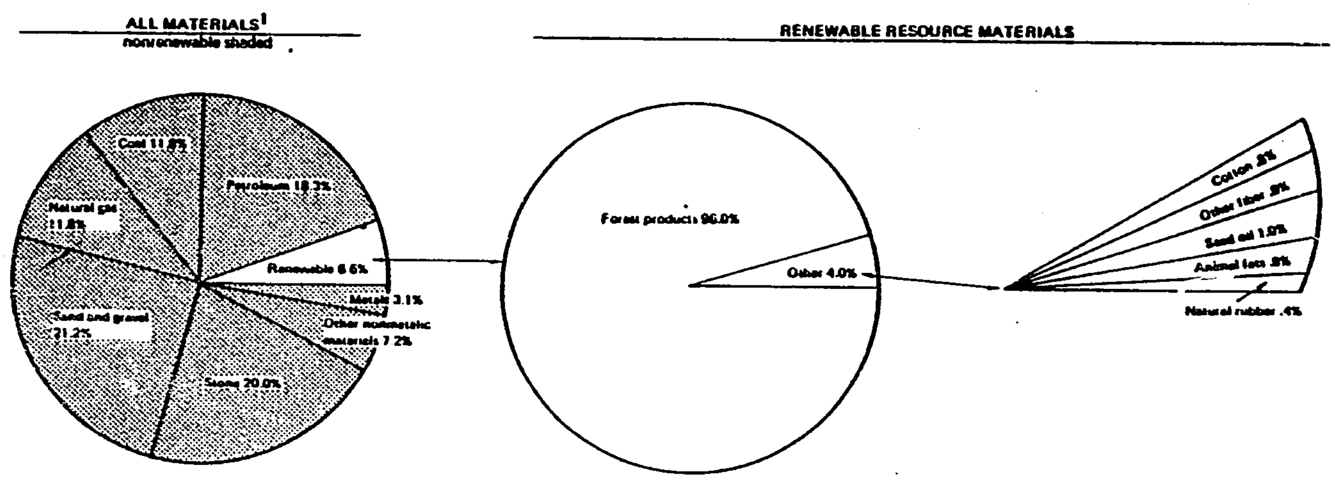

Figure 1.1 Usage of Basic Raw Materials in the United States
(% of Weight Used)

Source Report of the National Commission on Materials Policy, June 1973, cited in Ref. 3.

1.2.3.4 Natural Fibers

Fibers, according to Webster's Unabridged Dictionary (2nd Edition), are any substances which may be separated into threads or threadlike structures. Natural fibers are produced in nature and extracted from these natural mineral, animal, or vegetable sources by man. (Man-made fibers such as rayon or nylon may be synthetic -- produced from man-made chemicals -- or organic -- produced from naturally derived chemicals). Presently, the most common natural fibers are the vegetable fibers cotton, flax, kapok, jute, hemp, and sisal; the animal fibers wood and silk; and the mineral fiber asbestos.

1.2.3.5 Initiatives

The term "initiatives" used in this thesis will follow the same definitions used in the Principal Study. Initiatives:

> "... mean steps, policies, and programs that the U.S. government might take, adopt or support to aid developing countries in utilizing appropriate technology for renewable resources for the benefit of people -- in particular the poor majority -- in those countries." (19)

1.2.3.6 Mechanisms

A broad definition of mechanisms will be used in this thesis to embrace a variety of measures used to implement an initiative. Such mechanisms may include organizational forms such as the linking of research institutions like the Indian Central Building Research Institute in Roorkee with one or more such institutions in the U.S. They may also include programs such as a research grants program within the U.S. to work on problems within or of benefit to DCs, or legislation which will support the various initiatives.

1.2.3.7 Materials and Products

Although many materials can be made with agricultural residues, the specific focus of this thesis will be on those materials which are not used for, or as, products of an energetic nature (e.g. fertilizers, food, feed, and fuel). Such materials can include materials used in -- or as -- products for building or construction, packaging, filtering, or fabricating.

The term "materials" is defined as a substance such as coconut shell dust which is produced from agricultural residues. The term "products" describes the finished good, like plastic furniture in the coconut shell dust instance, but it can also be a material, as the cement produced from rice hulls is both a product and a material for making further products.

1.2.3.8 Boards

There appears in the literature a wide variety of terms describing the boards which can be made from agglomerations of agro-wastes and natural fibers -- as well as from wood wastes. Particleboard consists of wood, or other material, particles ranging in size from, say, sawdust through large flakes. These particles are bound with resin and then pressed or extruded as sheets. Depending upon the material or materials used, and the compression used, particleboards will vary in weight, usually from 25 to 50 lbs./cu. ft. (400 to 800 kg./m^3). Particleboards can be used as is -- with perhaps some sanding -- or covered with a veneer for furniture and cabinets, as well as for panels for interior and mild exposure exterior surfaces. (39)

Fiberboards are used principally in packaging and furniture, but have extensive applications in the building industry. They are made in a manner similar to paper, and some varieties are called paper board, corrugating board, and fluting board.

1.2.4 Other Waste Uses and Products

There are a number of other waste uses and products which are related to the major focus of this thesis, but which are not considered in much detail. The following brief descriptions of three of these areas point to the need for continued research into the entire range of renewable resources processing and product possibilities in order to determine the most efficacious response to each situation. (See also Sections 4.5.3 and 6.2.2.)

1.2.4.1 Timber Wastes

Research has shown that considerable effort is -- and has been -- underway to minimize timber wastes. Much of the impetus for such efforts has come from within the industry itself in its endeavors to use as much of the timber brought to the sawmill as is possible. In most timber concerns, lumber* represents only about half of the log volume which enters the sawmill; the remaining half is composed of chips (30 percent of log volume), sawdust (10 percent), and bark** (10 percent). (4) In developing countries, the small sawmills often use such residues as fuel, while the larger ones employ techniques similar to the ones used by the industrialized world's timber companies

*Lumber is sawn timber. Timber means trees and logs.

**Bark has little use value except as a fuel or garden mulch. (4)

and are producing panel boards, etc. from these wastes. Because of the high cost of binders (see Section 3.2.7) and economies of scale, smaller-scale production of panels or boards from such wastes is ordinarily not viable economically. (7, 38, 40)

Some of the national and international efforts dealing with timber residues as a renewable resource include: 1) The Committee on Renewable Resources for Industrial Materials, U.S. National Research Council (NRC) completed a study in 1976 (3) dealing primarily with wood and timber wastes, for the understandable reason that "forestry products by weight ... account for approximately 96 percent of the renewable resources consumed" in the U.S. (3) (See Figure 1.1). 2) The U.S. National Commission on Materials Policy completed a study in 1973 (14) solely on timber as a renewable material. 3) The Agency for International Development and the Forest Products Laboratory of the Department of Agriculture sponsored a Conference on Improved Utilization of Tropical Forests in May of 1978. (5)

In light of these efforts and time limitations, this thesis will in general not consider wood wastes. In certain instances, technologies will be pointed out, such as board or paper making, which are applicable to timber as well as agricultural residues or natural fibers.

1.2.4.2 Medicinal and Chemical Products

Medicines and chemicals are products which are not specifically covered in this thesis. This is not to say that research into capital-saving technologies for their production is unwarranted. Medicinal and chemical products derivable from agricultural wastes and natural fibers have been and continue to be reported in botanical publications, and pharmacopaeia, and are frequently noted in publications like The Wealth of India -- Raw Materials. (41) In addition, while there may be a wealth of unresearched "native remedies" in many developing areas, relatively little work has been done to record and analyze these "remedies." (42) For some of these "remedies," requirements of public safety and health, and proprietary processing information limit opportunities for commercial production on scales similar to those looked at herein.

Both chemical and medicinal industries frequently have economies of scale that inhibit small-scale, labor-intensive processes; nevertheless some efforts are now being made to redirect pharmaceutical production towards small- or intermediate-scales in the United Kingdom under the direction of the Intermediate Technology Development Group (ITDG) (43), in Sri Lanka in cooperation with Delft (the Netherlands) University's Center for Appropriate Technology (44), and in the People's Republic of China (China), where students at Peking University are assigned syntheses of low-volume, high-cost drugs in place of laboratory experiments. On the grounds of Peking University, a small pilot plant has been constructed, and the students produce drugs for use within China. (12)

1.2.4.3 Traditional Products

During the state-of-the-art review, attention was not directed to traditional products, or handicrafts, like floormats, baskets, and tapa cloth. Many of these products are not made from agricultural residues or from primary natural fibers. Fibrous plant matter, not plant fibers, are used to make many of these items; for example, the leaves of Pandanus thurstonii (viovoi in Fijian) are used in Fiji for most matting and baskets. While such products are very useful in the cultures where they have developed, problems of durability and production efficiency will need to be overcome to maintain or expand their market shares. Otherwise, markets for such products may recede as those of woven cane or corn leaves once used in chairs in this country have receded.

The production efficiency of many of the all hand-made traditional products is very low in comparison to their market value. For example: in Fiji a sleeping mat* requires over one person-week to produce, including preparation of the voivoi. Its market price is less than F$20.** While such a price could guarantee a good living in many parts of the developing world, and does provide a cash supplement to the livelihood of Fiji's mat-makers, the price reflects non-pecuniary factors. Most of the mats produced in Fiji are used for traditional ceremonial exchange or domestic consumption; they are not usually produced primarily for sale. The market price reflects more what tourists, relatively well paid civil servants, and others in the cash economy are willing to pay. While supply/demand studies have not been undertaken, it is doubted that such a "high" price would exist if mats were only produced for sale. Therefore production efficiency would need to improve in order to maintain the same income level. (45, 46).

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*Ibe ni moce. It is a thin 4' x 6' (approx.) mat of woven 3/8" strips of voivoi; frequently it has a yarn fringe which costs about F$2-$3 per mat.

**F$1 is approximately equal to U.S. $1.25.

Increases in production efficiency do appear to have occurred in some areas of the world. However, the markets for these products are frequently adversely affected by the products' limited durability when compared to the durability of the synthetic materials which are used in competitive products like carpets, handbags, mattresses, and plastic furniture. A part of the solution to increasing the durability of these traditional products will involve research into material improvement similar to that discussed in Chapter 4. Another part of the solution will involve the development of product designs which help to extend the life not only of the product itself but also of the materials from which it is made.

1.4 ORGANIZATION OF THESIS

Chapter 2 is a review of the needs for appropriate technologies for the production of building and other materials from agricultural wastes and natural fibers, and the considerations which will affect their implementation. In Chapter 3, current state-of-the-art technologies for utilizing agricultural wastes and natural fibers are reviewed, on a crop-by-crop basis for ease of reference. Chapter 4 discusses areas for further research and suggests the initiatives the United States may take to implement the technologies and augment research. Institutions which may be of use to, and mechanisms for, the furthering of the initiatives are described in Chapter 5. Much of the discussions of initiatives and mechanisms are drawn from the findings of the ATRRU Study. Chapter 6 summarizes the discussions in the earlier chapters and discusses future steps in this area.

2. NEEDS AND CONSIDERATIONS

2.1 INTRODUCTION

In various UN seminars and conferences over the past decade (47) it has been noted that developing as well as developed countries cannot continue to depend indefinitely on many of the raw materials that are currently used, and that agricultural wastes and natural fibers which are plentiful in most developing countries can substitute for these currently-used raw materials. 1972 estimates of the amounts of some of these wastes are presented in Table 2.1.

Historically it has been pointed out that progress towards increasing the use of agricultural and timber wastes and natural fibers in developing countries has been slow, even in countries with sufficient timber and non-renewable resources for domestic needs. (7) Many such countries, while not self-sufficient in wood, mineral, and other resources, have substantial quantities of agricultural residues and non-wood fibrous materials which, more often than not, they fail to utilize. (30, 40, 48) If suitable products can be identified which use these materials and if, as a result, new industries can be established, dependence on decreasing world timber reserves and non-renewable resources can be reduced and opportunities for employment can be created.

2.2 BUILDING MATERIALS

The primary non-feed, non-food, non-fuel products from these wastes are materials for building and construction which are much needed in developing countries. Most developing countries continue to rely heavily on imports of building and construction materials, which

Table 2.1

Estimated Availability of Specific Non-Wood Plant Fibrous Raw Materials, 1972. (Values are for potential availability with present collection methods.)

Raw Materials	Quantity (bone dry metric tons, thousands)	
Sugarcane bagasse	55,000	
Wheat straw	550,000	
Rice straw*	180,000	
Oat straw	50,000	
Barley straw	40,000	
Rye straw	60,000	
Flaxseed straw	2,000	
Misc. seed straws	3,000	
Subtotal, straws		940,000
Jute fibers	4,425	
Kenaf and roselle fibers	1,674	
Sisal fibers	648	
Abaca fibers	92	
Henequen fibers	164	
Subtotal, fibers		7,003
Reeds	30,000	
Bamboo	30,000	
Papyrus	5,000	
Esparto and Sabai Grasses	700	
Cotton staple fiber and second-cut cotton linters	14,500	
Subtotal, grasses, reeds, etc.		80,200
Estimated Total		1,027,203

Source: Reference (49)

*Does not include the 60,000,000 tons of rice hulls generated annually. (50)

account for 14 to 40% of their construction costs (48) and about 60% of their materials costs. (51) The scale at which these materials are imported and their effect on foreign exchange may be gauged from information covering a number of developing countries over various periods between 1955 and 1965. These data show that in most countries in Africa, Asia, and Latin America, the value of "imported building materials ranged from 5 to 8% of the total value of imports, yet expenditure on building and construction materials is from 3 to 5% of the gross domestic product (GDP)" in developing countries. (35) From these and newer but less detailed (51) data, it is clear that building and construction materials, when compared to other industries, use up a disproportionate share of foreign exchange.

The production within developing countries of building materials and materials used in construction from indigenous agricultural residues and fibrous materials is also necessitated by demands in those countries for housing and low-cost shelter which are caused by both population growth and urbanization. Building programs which utilize such materials will not only cut down on the import content of structures, but, in most instances, their absolute cost as well. (11, 52) Part of these cost reductions will be derived from the use of more standard size and quality materials. The use of artisanal methods in building construction generally leads to higher costs (51).

The most important aspect, probably even more important than the foreign exchange or balance of payments aspect, is that the use of these wastes and natural fibers in the building materials industry has an important multiplier effect both on employment and income, and thereby plays a dynamic role in a country's development. (3, 11, 13, 35) In addition, building materials from residues can provide another market for those wastes which may not be useful for food, feed or energy purposes.

Along with encouraging new industry at the village level, the building materials industry can also provide employment during the periods when less labor is required for agricultural production. Construction output may fluctuate considerably, especially at local levels. The supply of building materials must be adjusted to meet the situation. In agricultural areas, the trend is to build or at least to purchase materials during the slack season after harvesting so that, after several years or seasons, the villager will have acquired enough materials to finish building. Normally, demand fluctuations are accomodated in the building materials industry by adjusting the level of output, by stock changes, and by importing or exporting to meet requirements. Adjustments of output are often difficult to make in industrialized countries owing to the use of capital-intensive production processes which require high output for economic operation. Stocking adds cost, and importing when shortages occur or exporting surplus production requires established channels and markets, none of which are generally found in the rural areas of most developing countries, and often not in their metropolitan centers. (35) However, rural, agriculturally-based industries which use crop residues for building materials manufacture may not suffer from these constraints.

2.3 HOUSING/SHELTER: URBAN VS. RURAL*

Most of the world's developing countries lie in the tropics and sub-tropics, and use local organic materials as primary sources of products for housing, other forms of shelter, and as the components of other industries such as transportation and storage. Traditional uses of organic materials are based on their availability and renewability -- elements which also determine their cost. A living tradition of methods and skills has grown which enables families to fulfill their basic shelter and other needs with simple tools and devices, with little cost or sophistication of labor. The completed products of these activities are usually remarkably sensitive to the demands of climate**, and to the cultures and needs of the users. (11, 53)

The problems associated with continued use of renewable resources are caused primarily by population growth, rural-to-urban population shifts in growth situations and, technically, the inability of organic materials to respond to performances required under changed conditions of use. In cities and urbanizing areas, organic materials are no longer plentiful and cheap. Such areas impose stricter demands on both material and performance and the methods and skills than were traditionally imposed. In the housing/shelter industry, for example, public concern for health and safety has resulted in new building code requirements.

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*The author gratefully acknowledges the contributions of J. P. R. Falconer to this chapter, particularly for portions of Sections 2.3 and 2.5.4. (53)

**Until recently, climatic design was taught as a separate aspect of architecture and engineering. (54)

Operating under socioeconomic conditions that discourage the use of self-help and mutual aid in building organization, and having the skills necessary for building with traditional materials lost or diffused in the urbanization process, the urban dweller also has little time, energy, or interest to invest in the cyclical routine of maintenance, repair, or replacement that is characteristic of rural life. Thus, housing quality in cities and urbanizing areas suffers with the continued implementation of rural techniques, forcing those responsible to search for new materials and methods based on their new use requirements. For example, concern for the spread of fire in high-density areas has resulted in the prohibition of grass roofs and the substitution of manufactured materials such as metals and cement-based products.

Substitution of manufactured for organic materials in attempts to meet the different performance needs of urbanization has created its own severe set of problems. For one, to use the housing industry example again, building costs have risen in direct relation to the higher cost of manufactured materials, both to the user and in terms of foreign exchange. Since cost considerations are of dominant concern, the reduction of material content in a building more often than not overrides other important design criteria, such as functional requirements, structural stability, adequate space standards, and other qualities of building performance. For examples: wide overhangs are essential to comfort and use in the tropics, but cannot be afforded in low-cost housing built with expensive manufactured materials; the quantity and/or quality of structural materials makes buildings extremely susceptible to failure in storms, earthquakes, and other high load situations. And while the properties of inorganic manufactured materials may meet certain performance requirements, such as fire-safety and durability, better than those of organic materials, they suffer by comparison in other important respects. For example, the low thermal mass and good insulation properties of plant materials make them excellent moderators of tropical climates, and may serve to reduce or eliminate interior artificial climates, especially air conditioning. (55) Agricultural waste materials are also more weight efficient than timber products: particleboards from timber materials cannot readily and commercially be made to weights less than 120% of the weight of the original timber material; with flax shives or bagasse, for instance, a board of acceptable strength can be made that is less dense than the raw materials. (6) Building methods based on the use of traditional materials can be less costly than those that involve a higher technology, and overall building quality is usually more suitable and responsive to the use patterns and needs of the local users. (11, 55)

2.4 AGRICULTURAL AND INDUSTRIAL DEVELOPMENT

The domination of a country's economic structure by the agricultural sector was at one time taken as the structural characteristic of underdevelopment or backwardness in terms of economic growth, income per capita, income distribution, etc. Additionally, and perhaps more pervasive, the fact that the "developed" countries had passed through phases in which agricultural production declined in relation to the manufacturing and service sectors helped lend substantial support to the contention that rapid economic development could only occur in the face of massive structural changes in the developing countries. In the past, many developing countries adopted the belief that such development could be accomplished in two ways. Either real economic resources (such as capital and labor) would have to be transferred from agriculture to industry, or agricultural resources would somehow have to subsidize industry. In a sense, the agricultural sector was regarded as the foundation upon which industrialization and rapid economic growth would be based.

In the last decade however, a new view of economic development has gained favor. This view emphasizes the interdependence of all units and sectors of the economy, and the need for integrated growth to meet a number of broader economic and social objectives, in order to obtain and sustain high rates of overall growth. (56) Certainly, both earlier approaches to development are useful, depending upon specific situations. From an overall policy standpoint, according to UNIDO (56), the problem is solely one of influencing investments in various industries with the distinction between an "agricultural" or an "industrial" policy having little relevance; as stated by P. Streetan:

> "Even at the margin, the choice is not between industry and agriculture; it is between projects ... many of which, like processing local raw materials, will cut across the dividing line between industry and agriculture. Priority must be given to a form of industrialization which is consistent with a strategy of rural transformation." (56)

This new opinion of economic development resulted in part from noteworthy instances where insufficient attention to one sector has been detrimental to the development of the other. (57)

Agro-industries -- industries based upon raw materials from agriculture -- perform a significant role in spurring production, productivity, and product diversification in the primary sector, and can be strategic ingredients to the development process. Many of such resource-based industries have proved to be pioneer industries in DCs, as they were in the industrialized countries generations ago. (3) Agro-industries, using raw materials in the form of renewable resources from farms, prairies and grasslands, forests, and oceans, rivers, and lakes, may be classified into two types of processing industries, food and non-food. Food processing industries increase the quantity and perhaps the quality of food through waste reduction, perishables preservation, and animal feed production from residues, and in this way, satisfy a larger demand for food from a given amount of land, energy, and other inputs. Non-food agro-industries chiefly satisfy man's needs for clothing and shelter, energy, and commodities such as natural fibers and aligned fibers for the textile and cordage industries, as well as rubber, wood and wood products, paper, and leather.

Almost all of the non-food agricultural raw materials can be processed to a greater degree than food raw materials, and thus the proportion of value added in this type of processing tends to be higher than in food processing. Another aspect is that non-food agro-industries, in light of increasing prices for synthetics and man-made fibers used in combination with natural raw materials, can maintain a constant price structure relative to the synthetics and other materials because of relatively constant extraction costs, and the improbability of a biomass resource cartel. The production of processed agricultural products also catalyzes farmers' participation in the market system and contributes to the transformation from subsistence to commercial agriculture.

In most DCs, three-quarters of the population live in rural areas, most depend upon agriculture for their livelihood, and much of their labor is underutilized. Even at the most optimistic rates of growth, the ability of the urban, industrial sector to absorb rural labor is limited, leaving the bulk of the labor force in DCs dependent upon agriculture and related activities for development. Additionally, developing countries cannot continue to depend upon increasingly costly imported raw materials. Many such materials can be replaced to some extent by making use of agricultural wastes which presently go un- or under-utilized, and of natural fibers which have more potential uses than current markets provide.

As noted earlier, cost constraints will, for the foreseeable future, dictate that building and other materials be based primarily on natural locally available materials. The development of non-food agro-industries using available labor and fibers and wastes from agriculture can provide a stepping-stone in the process of industrialization and supply materials needed by rural peoples. Such industries can also provide assistance in meeting the housing needs of the urban poor through the supply of low-cost materials.

Referring to the special problems of the hill people of northeast India -- which are comparable to rural peoples in many developing countries -- Shri L. P. Singh, Chairman of a workshop on the application of S&T to the development of the northeast area, said "the people remained long outside the mainstream of national life," and that "the economic development of the tribal people is at present almost entirely linked up with agricultural and allied activities." (58) In discussing industrialization of the area, Singh noted that techniques should be developed which enabled the people to improve their traditional products, and stressed the development of technologies "based on available raw and <u>waste</u> material[s]." (emphasis added)

Many developing countries have economies which are based on a small number of crops. Such is a very tenuous foundation: reliance upon a small number of plants carries great risk. Monocultures or near-monocultures are vulnerable to catastrophic failure from disease or weather and climatic vagaries. Additionally, such crops are usually grown for a single product (such as copra from coconuts for its oil and meat, and sugarcane for sugar), making them vulnerable to changing world market conditions. (11, 56, 59) The apparent advantages of the plants that are widely cultivated in DCs over those that are not has often resulted from the disproportionate research efforts directed towards them. (12, 60) Many species, such as the marama bean of the southern Africa or the winged bean of New Guinea and southeast Asia (60), which could be important for a country's economy were disregarded during the colonial period when demands in Europe and North America, along with those of resident Europeans, determined local research priorities. Even after independence this research pattern has changed little in many DCs because of the preeminence of existing markets.

The variety of plant species in the DCs is impressive; among them may be a wealth of new products. In deciding upon the potential of each, it will not be enough to consider only traditional needs and markets. New materials will be required in the future. Changing conditions are already creating demands for new products from previously underexploited plants like the coconut tree (discussed in Section 3.2.2). As the pressures increase for the exploitation of renewable resources, more of them will be needed. The use of crop wastes, especially those from crops outside or on the margin of world markets, and natural fibers in the production of new materials can lessen the effects of world agricultural commodities market price fluctuations (61) and could aid in crop diversification by increasing the demand/use potential for crops now of secondary or tertiary importance. (62)

2.5 OTHER NEEDS AND CONSIDERATIONS

2.5.1 Economic Factors

The successful production of glue in Ghana from cassava and plantains, and the success of a pilot cement plant using the Mehta process to produce cement from rice husks, along with other examples cited in Chapter 3, indicate that the conversion of some agricultural wastes into useful materials can be profitable and employment generating. Wen-Yuan Huang, an agricultural economist at the University of Hawaii, has developed an economic framework for analyzing by-products utilization. (63) While Huang's framework deals with the use of agricultural residues to produce food/feed or fuel (fertilizer) products, and is evolved from considering only two farm wastes, namely pineapple and dairy wastes, it contains flexible parameters which can be extended to materials production from multiple farm types. The model is said to have value for use in "evaluating utilization, in searching for optimal use, and in planning future use of the by-products under differing economic settings." (63)

According to the report of UNIDO's Expert Working Group on the Production of Panels from Agricultural Wastes: "... the need was stressed for careful economic surveys and feasibility studies prior to introducing processing plants." (38) While the importance of such analyses and surveys cannot be overestimated, their value is directly proportional to the output capacity of a producer. Small rural producers may have a ready understanding of their market and costs and can be quite flexible in their response to them without the expense of surveys. The United Nations Department of Economic and Social Affairs endorses the small-scale production of residue materials as a first step in industrialization so that mistakes in product manufacture can be reduced prior to large-scale industrialization. (48)

2.5.2 Environmental Factors

In traditional construction, the climate determines the materials which are readily available for use in building and has helped shape local traditions of building. These have in turn governed the form and character of traditional structures. (35) The complete classification of climatic regions was worked out over a quarter of a century ago by Köppen and Geiger. (64) While classifications such as this are capable of increased detail and accuracy through the use of earth observation satellites, currently available information can indicate areas for concentration of research in specific types of residues and products. By ascertaining what types of agricultural products and natural fibers are or can be grown in which areas, and what types of building and other materials are used in which areas, the types of specialized/concentrated research that could be done to start or expand the production of agricultural residue materials can be indicated.

In many areas agricultural wastes are a pollution problem, with piles of residues decaying, providing feeding and/or nesting grounds for pests that not only harm future crops, but also human life. It has been a fact of life in coconut plantations that excess husks, leaves, stumps, etc. -- for which there was no immediate local use -- are cleaned up and burned to keep down coconut pests such as the rhinoceros beetle and human pests such as the mosquitos which breed in the water which collects in upturned husks, leafstalks, etc. (65) Piles of such residues also provide nesting grounds for rats which can carry disease organisms and which also attack some crops as well as humans. Putting as much of these residues to work as possible -- as materials, as fuels for the materials processes, as soil amendments, etc. -- will eliminate many of these hazards, possibly at lower cost, conceivably at a profit, than current practices.

2.5.3 Political Factors

While there appears to be a need for the various building materials industries' output and production levels to be increased to a large extent (52), in order to accomplish this, "a more comprehensive developmental and industrial strategy designed to meet [both] basic socioeconomic needs and to achieve adequate growth of technological capability in developing countries is needed." (66) Yet, in many countries there is frequently opposition to industrialization which uses local materials and is small in scale.

This opposition frequently comes in the form of "existing policies ... [which have] hitherto favored the growth of large-scale and medium industries in the organized urban sector," (67) and may be alleviated by the development by each developing country of an overall technology plan which embraces the evaluation and improvement of traditional technologies, the application of modern science and technology through national research and development programs, along with the acquisition, use, and adaptation of foreign technology. (67)

A typical policy obstruction arises from building codes which, for reasons of fire protection, decay prevention, and/or structural soundness have been frequently written in product- or technique-specific language rather than performance-specific terms. An example of this is in the building regulations in Fiji made pursuant to Section 39 of Chapter 91 of the Laws of Fiji. Regulation 76 of Part 10 (Materials and Workmanship) reads as follows:

> "All aggregates used for concrete work shall consist of clean natural river gravel or crushed stone of approved grades and sizes, and shall otherwise conform to the requirements of Part 18 [which deals with concrete construction] of these Regulations." (68)

Legal language such as this inhibits the introduction and use of new and non-standard products, including materials from agricultural residues. Work towards the modification of inadequate and restrictive building codes has been recommended by at least two United Nations conferences (6, 67) Work in this area has been done by CICSENE of Turin (Torino), Italy. (This group cooperates with DC organizations regarding town planning and building codes, with emphasis on siting and construction/design provisions that allow dwelling places which can be built by/for all facets of society.) (69)

In some developing countries there frequently exists a widespread belief that "imported is better." A major effect of this attitude is a lack of a tradition of indigenous science policy advice on major national questions, resulting in a lack of government- or industry-wide commitment to research as a means of solving these questions. However there is increasing evidence of new channels of communication between some DC governments and their countries' scientific communities. (12, 70) Because of the broad potential benefits to significant numbers of DC people and to distributed economic development, research and development into appropriate technologies for producing agro-waste/natural fiber materials will need ties with or support from governmental development programs. Agricultural research programs contained in development plans, which, like Zambia's, call for "strong emphasis [to] be given ... to establishing and maintaining research facilities and programmes that will have the maximum impact in improving the productivity of the rural areas" (18) will need to be expanded to include product development as well as productivity improvement.

Another source of political opposition has developed from international trade in industrial products. An example of this is provided by one multi-use agricultural crop, the coconut. As will be shown in the state-of-the-art review, Chapter 3, coconut plants and their fruit can be made into many products of use to developing countries, but these have been inhibited by demand from industrialized nations. "Coconut products were, separately, taken away 'upstairs' as raw materials; and arguably less suitable and certainly more expensive synthetic finished products were sold back ..." (71)

2.5.4 Social and Community Factors

As mentioned earlier, a major factor governing the introduction of technologies which convert fibers into usable products is likely to be product acceptance. (38) The pejorative connotations associated with the term "wastes" could impede or inhibit product acceptance, and consequently the introduction of the technologies. Various answers are proposed in both U.N. reports cited earlier (38, 48), ranging from the training of sales and technical personnel and the publishing of products' technical and performance specifications, to the substitution of the word "residues" for "wastes." These solutions are of little value to the small-scale, low-volume producer, but the principle behind them should be communicated to prospective producers.

The purchase of building materials in most rural areas is usually limited to those manufactured items which fill a need that natural local materials -- which are free or can be obtained through barter -- cannot fill. Often, these are imported manufactures like corrugated roofing, cement, and connectors (nails, hinges, etc.). In introducing technologies such as those we have reviewed, the initial products will probably need to be ones which capture existing markets.

As has been pointed out by M. K. Garg (72), the social problems caused by resistance to disruption of traditional lifestyles including traditional construction techniques and materials, must be noted not only by industrial designers, architects, engineers, and materials scientists, but also by the regional agriculturalists. A national or even a regional agricultural policy must take into account not only the basic need to increase total food supplies, but also the need to improve employment prospects in rural areas, especially during off-seasons, and the need to earn more foreign exchange through agricultural export or reduction of imports. Both of these other aspects of agricultural policy relate directly to the need for useful products from agricultural wastes. Additionally, it is essential to encourage the establishment of small-scale industries to support the agricultural sector and to meet the basic needs of the local population.

The primary goal of international technical assistance should be to support the efforts of the assisted country to improve the quality of life of its citizens. Since people live in communities, proposed improvements must consider not only the effect of technical changes on individuals, but also the responsibility that one individual holds to other individuals and to the community at large. The community, in turn, has the right and responsibility to participate in its future by choosing the ways in which it will develop, and the methods for implementing development. Development implies change, whether by gradual transition, reformation, or radical transformation. Since change usually disrupts social patterns to some degree, the presumed benefits of technical improvements must be weighed against the uncertainties of these disruptions. In rural areas especially, if the community is not involved in the planning and implementation of projects, individuals will have little stake and interest in their outcome. It follows that, while the feasibility of a proposed new or improved technology must of course be clear from the outset to policy implementers, the need for and proposed applications of the technology must be based on shared desires and agreements of the community. Any development policy that fails to consider these factors is likely to fail to produce long-term and lasting improvements in life quality, and runs the risk of becoming one more "demonstration" project. (73)

In general, and especially in rural areas, villagers are not well organized to implement development projects, and education and training of local people to work toward their identified goals will be required. Individuals will need to be helped to participate, and this will be facilitated if project goals are clearly recognizable, and if the project itself is of a scope and scale of undertaking that encourages the organization of small groups of participants. Since development projects are costly in time, effort, and money, the small-scale project stands the best chance of avoiding waste, and can be abandoned more easily should failure be anticipated along the line. While one given technology will not necessarily be suitable over the range of climatic, cultural, and social conditions likely to be encountered within a country, the project should serve more than local interest -- that is, it should form part of an overall government policy, as uniform as possible over the country, so that national development goals can be more easily perceived, and so that inter-community jealousies can be avoided.

The production of materials from agricultural wastes and natural fibers involves social, economic, political, and environmental factors which affect the development and transfer of such technologies to the areas where they will be of most use. The discussions herein attempt not to reiterate those factors which are somewhat universal, but to focus upon impacts which are particularly relevant to the area of renewable resource utilization.

2.5.5 Paper

Paper is considered to be one of the essentials, if not a prerequisite, for modern existence. Reference has been made to the correlation between a given country's standard of living and its consumption of paper (74, 75, 76). Many developing countries, recognizing the importance of pulp and paper industries, are desirous of establishing their own to meet their growing needs. Even Fiji, a small developing country (population 600,000; area 18,333 square km.), is establishing large pine plantations to supply pulp and wood chips in the 1980's, initially for export markets, but potentially useful within its own economy. (77)

Paper consumption in the developed countries exceeds 100 Kg (220 lb.) per person per year, and has been increasing at about 5% per year. Corresponding levels in DCs range from two to twenty percent of this amount, with negligible rates of increase because population growth matches most increases in production. While it is difficult, and without a doubt questionable, to determine a minimum production level for development purposes, it has been estimated that a level of 20 Kg (44 lb.) per person per year would be a desirable goal as it allows for packaging for industrial uses. This production level is comparable to that produced in the developed countries early in this century. (74)

To achieve that minimum would require additional production of about 100 million tons, up to 30% of which needs to be long-fiber pulp such as presently obtained from softwoods, but which may be obtainable from other sources (see Section 3.2.6). These fiber requirements -- and the investment needed to meet them -- are staggering, given modern production and exploitation methods. However the agro-wastes and natural fibers shown in Table 2.1 far exceed their requirements (74); as discussed in Section 3.2.6, most of these residues can be used for producing paper, with bamboo providing needed long-fiber pulp.

It has been noted that there is little commercial advantage in mass production paper manufacture over smaller plants. (74) With such residues available in limited quantities at any given site because of their scattered nature, and with the generally limited capital resources and paper markets of many developing countries, there is a compelling need for small-scale production capability in developing countries.

3. REVIEW OF CURRENT TECHNOLOGIES

3.1 INTRODUCTION

In this chapter the present "state-of-the-art" in capital-saving technologies for processing agricultural residues is presented. The technologies are generally presented on a crop-by-crop basis so that individuals interested in specific crops may readily peruse those products or processes related to that crop. Exceptions to this organization are product-specific sections such as the one on paper making. Paper can be produced from many different cellulosic materials and is process, not residue, constrained.

The review started with a perusal of current appropriate technology publications for articles relating to the use of agricultural wastes and natural fibers to make products of a non-food/feed or non-energetic nature. What few articles which were available were widely scattered and not indexed under the headings of this chapter. Further investigation showed that this field is a relatively new one for concentrated, coordinated, research even though modern research efforts have been occurring since World War II into materials from agricultural wastes. The current preferred use for these wastes is for the production of energy, feed, and food stocks. Less than 10% of the agro-residue technologies listed in the 1978 United Nations Food and Agricultural Organization's (FAO) publication, Agricultural Residues: Compendium of Technologies (6), deal with non-fuel, non-food/feed processes; this compendium summarizes the information gathered in a world-wide survey conducted by the FAO.* A related FAO

*A useful bibliography on agricultural residues has been published by FAO. (79)

publication, Agricultural Residues: World Directory of Institutions (78), lists far more technologies, but fewer of them are concerned with non-food/feed/chemical/fuel uses. Furthermore, many of the technologies summarized in both publications reflect developed country activities and the needs and opportunities for research in those countries.

It also appears that only a relatively low proportion of agricultural residues and fibrous materials have been identified, tested, and utilized for manufactured products on a commercial scale. (6, 7) Successful large-scale commercial production from agricultural wastes and natural fibers has been limited to bagasse, flax, and linseed residues, and to European reeds. (6, 7) Most of the technologies listed in Agricultural Residues: Compendium of Technologies (6) are in the conceptual, laboratory or pilot stages, and those in the industrial stages are primarily in the developed countries.

The principal reason for lack of information on this subject appears to be the result of the paradigms of industrialized countries which have left most of their agricultural roots behind. In contrast, many developing countries have economies based predominantly on agriculture. And with agro-industrialization increasing during the past decade, many countries find themselves with growing surpluses of agricultural wastes available in large quantities and presenting serious problems of disposal.

Some of these residues are at present used as cheap fuels and soil amendment; only recently has research on and development of uses for certain agricultural wastes progressed to the point where the establishment of industries using them for the production of building materials has been seriously considered. The primary inhibition to the use of agricultural residues as raw materials for products results from their requirements for storage, which are greater than for traditional organic raw materials such as sawdust, and their need for preservation and extra or special fire-retardation treatments. Because many natural fibers have had well established uses as cordage, fabric, and in sacking and other packaging, little incentive has existed for diversifying their product possibilities.

Another limitation, which received considerable attention at the United Nations Meeting of Experts on the Use of Agricultural, Industrial and Consumer Wastes in Low-Cost Construction (48) is that imposed by public opinion: the term "wastes" has pejorative connotations to most people, and could evoke consumer resistance to panels or other building materials manufactured from these residues. That meeting noted that a product's quality was the only valid criterion for its selection for given end uses, and that those who are concerned with specifications and purchasing should not be influenced by the raw material used in producing these products. This point was stressed in the introduction to the report of that meeting (48), and in the chapters of that report dealing with marketing and promoting such products. It has also been stressed in a paper on renewable resources for shelters, prepared for the Foundation for Cooperative Housing (11), and by UNIDO's panel on the Production of Panels from Agricultural Residues. (38) Of course, reports do not necessarily supercede cultures, and the initial introduction of these products may best be made in existing markets, as pointed out in Section 2.5.4.

3.2 STATE-OF-THE-ART: SELECTED MATERIAL AREAS

The balance of this section will review the state-of-the-art in research, development, processing, and industrialization for certain specific waste and non-waste fibrous materials. These materials have been selected on the basis of data availability, prevalence in developing world areas, and potential for viable research and development initiatives.

3.2.1 Rice

Rice, one of the world's primary cereal crops with over 300 million metric tons of grain produced annually in the world (50), is also a major generator of residues. Over 60,000,000 metric tons of rice hulls, frequently mixed with rice bran, and an estimated 30,000,000 metric tons of bran are left after milling the rice kernels. (30) An additional 180,000,000 metric tons of straw are left in the fields after harvesting. Utilization of the bran for food and feed uses was considered in the Principal Study. (19)

3.2.1.1 Rice Hulls/Husks*

The average composition of rice hulls is 40% cellulose, 30% lignin, and 20% ash; the ash is derived primarily from the silica present in the hull structure. Husks are not suitable for use as animal feed because they have little if any digestible protein and are abrasive. Compost fertilizers made from rice husks are said to be as good as farmyard manure (80), and the hulls can replace two-thirds of the gypsum normally required for alkaline soils. (81) Their use as raw material in the production of paper goods is precluded by their

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*The terms "husk" and "hull" are used interchangeably in this thesis.

high ash and lignin contents in spite of their relatively high cellulose content. While small proportions of the hulls are used for low-value purposes like chicken litter, animal roughage, and pesticide carriers, most of them are burned -- either openly as trash or in small quantitites for their heat value, which is about half that of coal on a weight basis. (82) If all the energy requirements of rice milling were to be met by burning the hulls, only 80 percent of the hulls would be utilized (83), leaving the remainder free for other uses. The ash obtained from such burning has little fertilizer value. (82)

Research activities aimed at identifying potential uses for rice hulls have been going on for over 60 years. Most of these efforts have attempted to take advantage of some properties of the hulls themselves, such as their fuel value, their abrasive character, or the absorbent quality of the fuel ash as a filter. It has been reported (48) that studies examining the technical and economic feasibility of various uses which involve more than one of the properties of rice hulls have recently been completed. These uses may be classified as follows:

- Measures which make use of both the energetic and silica contents of the hulls;
- Measures which make use of both the textural and structural characteristics of the hulls; and
- Measures using both of the above concepts.

"The most promising approaches to the solution of the problem of rice hull disposal fall into (these) two basic categories." (48)

Research into the first concept has been directed primarily toward the manufacture of cement or pozzolana* by the controlled combustion of the hulls, using the heat of combustion to produce cellular and amorphous silica. The second concept encompasses research into abrasives, fillers, and filters. In the United States, VITA Volunteer Phil Cady has shown through his research that rice hulls can be used to make hydraulic cement (84), and Professor P. Kumar Mehta of the University of California, Berkeley, has developed a furnace to control the burning of the husks, thus producing a "highly reactive black ash which, when mixed with lime** becomes a rich black cement that ... is ... structurally as good as portland cement." (50, 85) Additionally, the lime content of the rice-hull-ash cement is less than a quarter of the lime content of normal portland cement, making it suitable for acidic environments. (86)

Professor Mehta's process, patented jointly by him and the University of California, (50, 82) has capital requirements for the basic furnace which "are very modest" and can be "applicable to small-scale rural-based plants." (86)

> "For instance, from the standpoint of very inexpensive small units, it should be possible to design small stoves ... as used for cooking food, provide a mechanism for controlled combustion of hulls, and arrange a centralized processing of ash into cement." (87)

Intermediate-scale plants, capable of burning one ton of hulls per hour, have relatively high installation costs -- $235,000 (1974) -- but it has been claimed (88) that 2 tons/hour and larger

*A siliceous material which, when finely ground and mixed with lime and water, forms a compound possessing cementitious properties.

**Either $CA(OH)_2$ slaked lime, or CaO quicklime. (82)

plants could pay off the invested capital in less than two years. The process equipment for such an intermediate-scale plant is simple, and according to Professor Mehta, "can be locally fabricated in most countries of the world." (87)

Figure 3.1 shows a typical process diagram for intermediate- or large-scale operations. The furnace designed by N. Pitt (88, 89) resembles an inverted cone, into which rice hulls are sucked due to the negative pressure maintained by an exhaust fan. From the furnace the hot gases and ash are taken to a boiler which acts as a heat exchanger, recovering the heat produced by the hulls' combustion in the form of steam. This is an important energy conservation aspect since the furnaces in plants of this scale are fired with fuels other than rice hulls. (Using the hulls for their fuel value only produces a considerably less pozzolanic ash.) Finally, the gas/ashes are passed through a multicone separator to remove the ash. The heated gas can be used to supply hot air to paddy driers in instances where the plant is near enough to rice fields or where paddy is dried at the mill prior to milling.

Based on Professor Mehta's laboratory investigations and the experiments run at a pilot-scale plant near Sacramento, it was discovered that totally amorphous silica in cellular structure could be obtained in rice hull ash produced by maintaining a combustion temperature below 500°C (932°F) for prolonged periods under oxidizing conditions, or instead, at temperatures up to 680°C (1256°F) for short hold times (less than one minute). The ash, consisting of a high surface area (50 to 60m^2/g by gas absorption), reactive, silica is a valuable material for making both high quality cements and

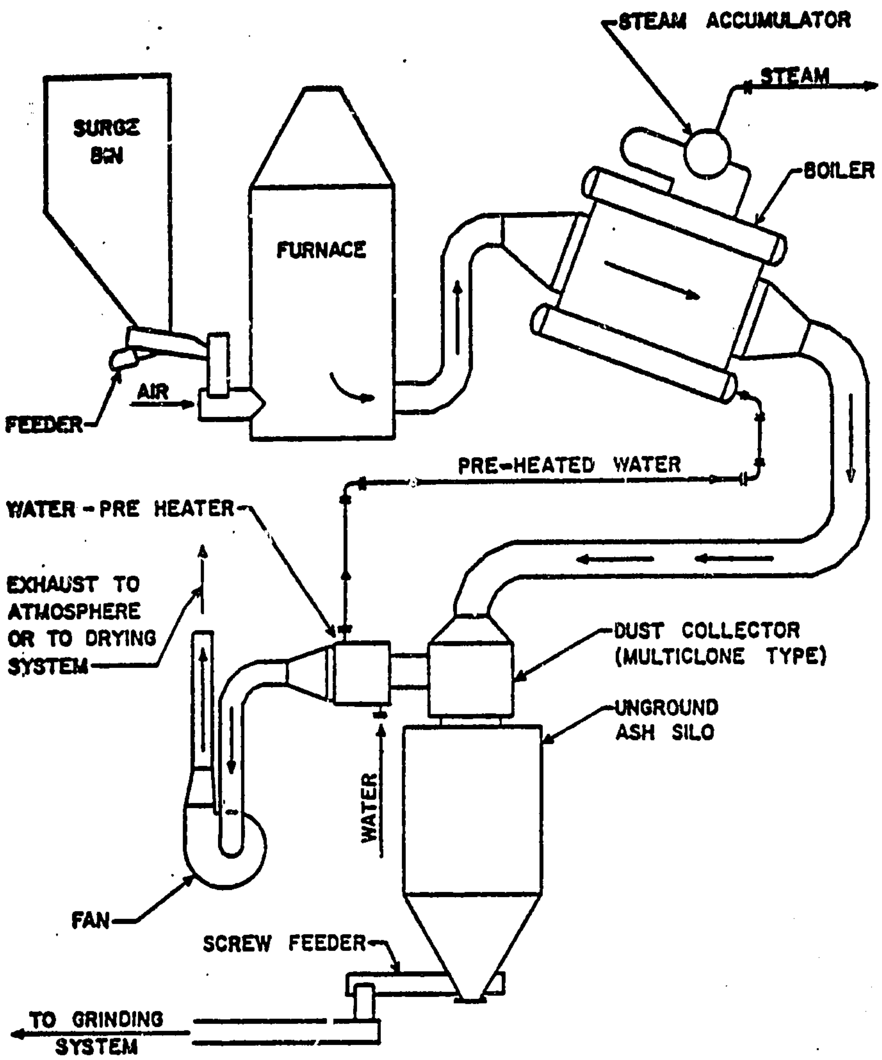

Figure 3.1 Schematic Flow Diagram of Plant For Producing Rice Husk Ash and Steam

Source: Reference (87)

reinforcing rubber. The primary consideration in designing small-scale stoves will be in optimizing the chemistry of the burning operation to produce the amorphous silica, which can then be made into hydraulic cement by simply blending the ground ash or inter-grinding the ash with lime. As shown in Table 3.1, such lime-rice husk ash cements develop adequate strength for masonry, plastering, and many structural activities. The data in Table 3.2 show that mixes of portland cement-rice husk ash yield cements with better strengths than straight portland cement.

As mentioned earlier, the low lime content in such cements makes them useful for acidic environments. Additionally, Mehta has found that they contain "practically no $Ca(OH)_2$ in the products of hydration" (87), or after setting. Ordinary portland cement hydration products contain about 24% $Ca(OH)_2$, making them very susceptible to acidic deterioration ($2HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O$; or $H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4 + 2\ H_2O$), as shown in Figures 3.2 and 3.3.

After examining the laboratory and pilot-scale plant, a full scale commercial plant using this process was built near a large rice mill in Stuttgart, Arkansas, and put into operation in 1976. This plant burns 7 1/2 tons of hulls per hour, and is designed to generate 50,000 lb/hr of 200 psi steam (50) (22,000 kg/hr. of 15 atmosphere steam (87)). Although the installed cost of this unit was estimated at $1.5 million, very low operating costs have resulted in competitive product prices.

The major drawback to the Mehta process is its use of fuels other than rice hulls, so that, unless some heat recovery system is included, the excess heat used in burning the hulls is lost. To our

Table 3.1

Compressive Strength of Mortar Cubes Made from Lime-Rice Husk Ash Cements*

Composition of Cement		Processing Method	Compressive Strength, psi (MPa)			
$CaO/Ca(OH)_2$	Ash: Lime (by weight)	blending/ intergrinding	w/c**	after 3 days	after 7 days	after 28 days
CaO	80:20	interground***	0.50	1500 (10.4)	3500 (24.2)	5130 (35.4)
CaO	70:30	interground	0.65	690 (4.8)	2050 (14.1)	3580 (24.7)
CaO	70:30	blended	0.70	360 (2.5)	1210 (8.3)	2170 (15.0)
$Ca(OH)_2$	75:25	interground	0.50	1100 (7.6)	2840 (19.6)	4160 (28.7)
$Ca(OH)_2$	70:30	interground	0.57	650 (4.5)	2400 (16.6)	3550 (24.5)
$Ca(OH)_2$	70:30	blended	0.77	500 (3.5)	1850 (12.8)	2900 (20.0)

*Tested according to the American Society for Testing and Materials (ASTM) Standard C109.

**Water/Cement.

***Interground means that both the rice husk ash and coarse lime are ground together, as opposed to blending the previously ground ingredients.

Source: Reference (87). ("Pa" is the new SI unit equivalent to "psi".)

Table 3.2

Compressive Strength of Mortar Cubes Made from Portland-Rice Husk Ash Cements (ASTM C109)

Cement Type	Compressive Strength, psi (MPa)			
	3 days	7 days	28 days	90 days
B-30*	4690 (32.4)	6690 (46.2)	8630 (59.5)	9390 (64.8)
B-50	3840 (26.5)	5740 (39.6)	8460 (58.4)	8920 (61.5)
B-70	3530 (24.4)	5210 (35.9)	6280 (43.3)	7370 (50.9)
Portland Cement (control)	3290 (22.7)	4780 (33.0)	6230 (43.0)	7010 (48.4)

*B-30, B-50, and B-70 represent the percentage of the mix which is rice husk ash (i.e., B-70 means 70% rice husk ash content).

Source: Reference (87).

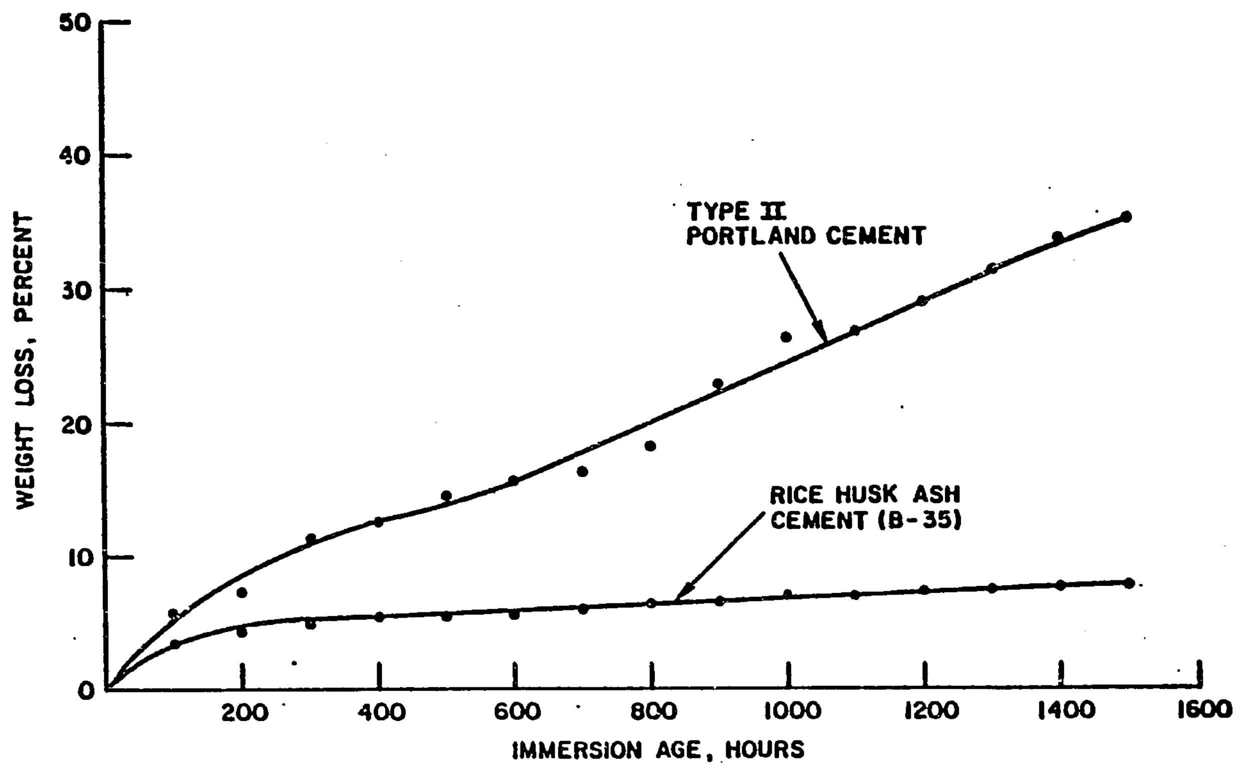

Figure 3.2 Relative Weight Loss of Portland Cement vs RHA Cement Concrete Cylinders (W/C=0.4), Continuously Immersed in a 5% HCl Solution

Source: Reference (87)

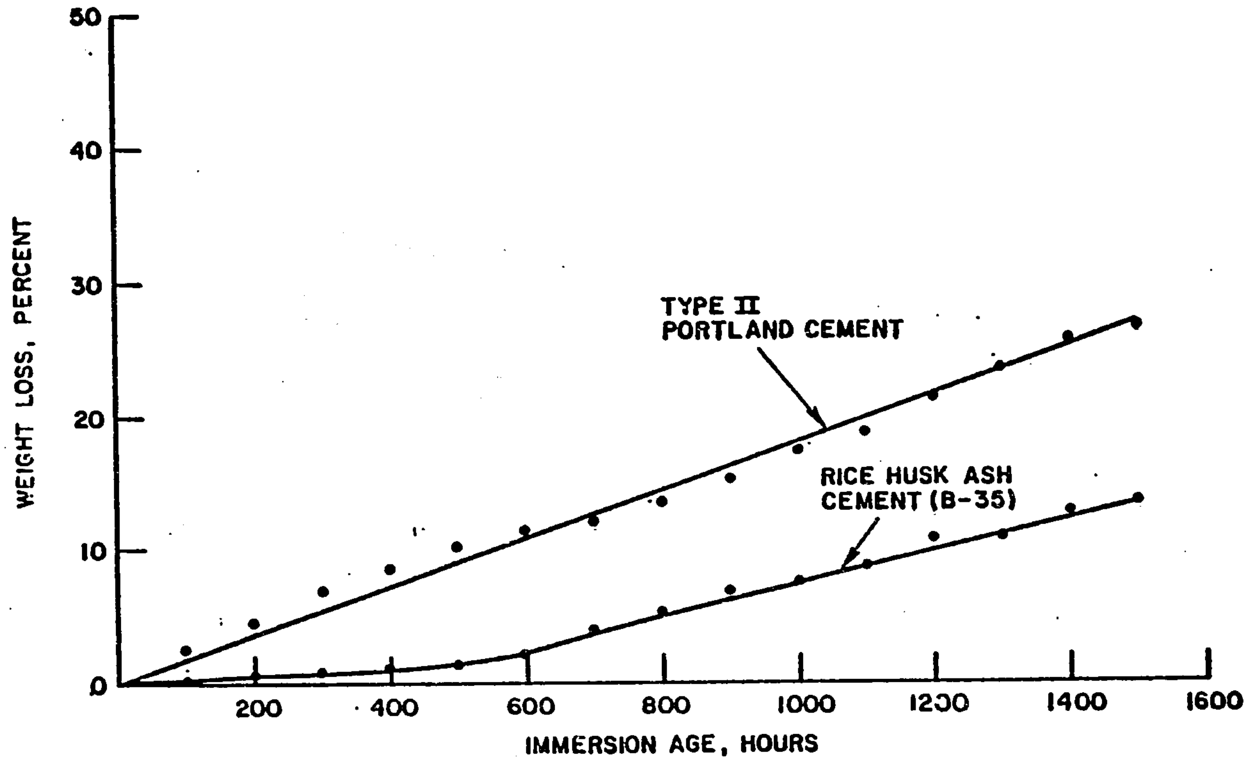

Figure 3.3 Relative Weight Loss of Portland Cement vs RHA Cement Concrete Cylinders Continuously Immersed in a 5% H_2SO_4 Solution

Source: Reference (87)

knowledge, no system has been developed to produce a high-quality cement when rice hulls are used as fuel because impurities result from presently available, uneven and incomplete combustion methods. (48)

Overseas, research conducted by the Asian Institute of Technology (AIT) in Bangkok has shown that village-burnt rice hull ash was a poor pozzolanic material, but that rice hull ash produced in a controlled burn -- 450°C for four hours -- conformed to ASTM specification C618-72 for pozzolanas. (90) While AIT's report cited one of Professor Mehta's papers, no mention was made of mixing the ash they obtained from their laboratory with lime, but only with portland cement. Their experiment was apparently aimed at determining whether such an ash could be used as an additive to ordinary portland cement, thereby reducing the need for importing or transporting that material. Results indicated that their laboratory-burnt ash can replace up to 20% of portland cement without any significant adverse effect on concrete properties. No explanation is available of the lower replacement ratio obtained by AIT's versus Professor Mehta's process.

In India, at the Central Building Research Institute (CBRI) at Roorkee, and at the Council of Scientific and Industrial Research's (CSIR) Regional Research Laboratory at Jorhat, research has shown that mortar cements, which need not be structurally as strong as most cements, but which are better binders, can be made from rice hull ash. (6, 8, 48, 78, 91, 92) The CBRI has developed two processes. One process requires the mixing of rice husks and clay with water, and then forming the mixture into balls which, after sun-drying, are fired in an oven-shaped brick kiln. After firing, the balls are ground into a fine powder, which can then be mixed in suitable proportions with lime and sand for mortar. The second process calls for mixing the husks with lime-sludge by-products from sugar processing, fertilizer production, tanning, or paper manufacture. The mixture is then fired and ground as the first, but does not need the addition of lime to produce mortar. (91) Both processes use rice hulls for fuel, and neither requires sophisticated plant, machinery, or techniques. (92)

The Jorhat process consists of burning the husk and then mixing the ash with binders to produce a mortar cement which has a seven day compressive strength of 26-35 Kg/cm^2 (370-500 psi). The laboratory-scale process showed projected costs (1976) of 100,000 rupees (approximately U.S. $12,500)* for a plant producing 5 to 8 metric tons per day. (8)

While the economic feasibility of using rice hulls to manufacture cement may be somewhat affected by economies of scale, cement production on a small scale using these or similar processes may prove to be economical in many regions because transportation of cement frequently accounts for over 50% of the retail price. (20) The scale of modern cement production processes in industrialized countries requires plant capacities of 5 to 10 million barrels** a year, while the "annual production of a plant based on the amount

*A conversion rate of 8 rupees per dollar is used throughout.

**The standard weight for a barrel of cement is 376 pounds (93), although the author used barrels weighing 1/4 ton while in Fiji.

of rice hulls typically available in a particular geographical area may be limited to 2 million to 3 million barrels." (48) With the aforementioned transportation difficulties, increasing fuel costs, and usually lower labor costs, developing countries' production factors may enable them to produce cement at lower cost, or at the same cost, but on a smaller scale than present practices dictate.

The Jorhat labs have found that the CBRI processes can be expanded to include the manufacture of building bricks from the mortar. The first CBRI process has been shown, at laboratory scale, capable of producing 5,000 bricks/day for an investment of (1976) 130,000 rupees (U.S. $16,300), and the second process can produce the same quantities for about 8% less. (6, 8, 78)

The Ghanaian Building and Road Research Institute at Kumasi has produced bricks from lime and rice hull ash without autoclaving. "The elimination of autoclaving lowers capital investment, and allows for savings in fuel," the result of which, in areas of Ghana where brick clays and firewood or other fuel is scarce, are bricks "which are cheaper than clay bricks." (48)

Another attractive approach to rice hull utilization and/or disposal "appears to be a manufacturing complex that converts part of the hulls into water-glass (sodium silicate) which is then used in the bonding of the remainder of the hulls into panel boards." (48) While this process may have a limitation similar to that of cement manufacture from rice hulls, that is, a significant portion of the hulls may go unburned or incompletely-burned, it is felt that the technologies are feasible, since furnaces which completely burn the husks have been designed, and unconventional processing techniques used in other manufacturing processes, such as fluidized-bed reactors, may be successfully applied to rice combustion. (48) Although this approach appears to be a relatively large-scale capital-intensive one(48), it illustrates one of the many possible uses for rice "wastes"; in addition, no external fuel source is required.

Unburned rice hulls mixed with cement can be used to manufacture hollow blocks that are comparable in strength and serviceability to traditional commercial hollow concrete blocks. These blocks can be formed by pressure molding in light-capital equipment like the CINVA-RAM. (94) Research into the production of these blocks, as well as similar blocks made from sawdust, wood chips, and coconut trunk particles, is being undertaken by the Forest Products Research Industries Development Commission (FORPRIDECOM) of the Philippines at Laguna. (95)

At the Institute of Standards and Industrial Research of Iran, research has been undertaken to develop an insulating light-weight concrete aggregate from rice husk ash. (96) Conventional concrete aggregates cannot suffice for this unless air, hydrogen, or carbon dioxide is introduced (entrained) into the cement paste; and special, low-density aggregates are often expensive. (48) The Iranian research showed that an existing composite-roof company, or a rice factory, with a low capital investment of (1975) U.S. $3,000, could produce 2,000 lightweight concrete roof blocks per day from 10,000 tons of hulls per year. (96) The investment is primarily for a press.

The United Kingdom Ministry of Overseas Development's Tropical Products Institute (TPI) has developed a method of producing a lightweight concrete aggregate using unburned husks which have been thoroughly soaked in water. (48) This method results in a product which has a somewhat low strength/weight ratio because the amount of cement in the mix is high -- four times the air-dry rice hull weight -- in order to obtain a workable mix (96); and the high moisture content of this concrete requires special consideration. (48) The low strength/weight ratio limits uses to non-structural materials, like roofing tiles, where lightweight materials can keep supporting structural elements to low levels and costs. TPI chose rice husks as their first material for investigation:

> "... because their disposal is difficult, they are frequently to be found in large quantities in one place and they contain only very small amounts of water-soluble cement 'poisons' -- chemicals* which slow down or retard the reaction of the cement fermentitious materials." (48)

TPI has developed a cement/hull block suitable for non-bearing wall construction that is also insulating. The thermal conductivity of rice hulls is similar to that of rock wool. (83) It is the intention of TPI to continue this type of research into other types of various low-bulk density vegetable wastes.

D. J. Cook, while he was at the University of New South Wales, Australia, found that rice hulls can be ground into a flour and used as a filler in polyester mouldings for plastic furniture. While rice hull flour as such a filler appears marginally satisfactory, it does compare favorably with the cellulosic fillers currently in use. (97)

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*Such as sugar and tannin. (Added by author.

Rice hulls, as is the case with many other agricultural residues and natural fibers, can be made into panelboards, particleboards, fiberboards, pressed boards, and sandwich panels. Tests conducted under the standard methods of ASTM specification D2017-63 have shown that such rice hull boards perform significantly better than standard wood particle boards in resisting rot, both with and without treatment. (98) But, according to Cook (97), further testing is needed into fire and sound retardance, into minimizing volume change due to water absorption in those processes which use water, and into water resistance of the finished boards. The manufacture of rice hull board, which can be mechanized to various degrees, may, according to some feasibility studies (99), prove to be a valuable industry in both developed and developing countries. It is clear from both Cook's research (97) and from the United Nation's meetings (38, 48) that to improve the versatility and marketability of such boards, development trials are necessary to fully define the performance characteristics of binders (cement, resins, sodium silicate) and of the production processes, as well as the different types of boards.

It appears that the opportunities for combining several technologies in one manufacturing complex merit further research. For example:

> "One [complex] would consist of a sodium silicate [water-glass] manufacturing facility producing sodium silicate from rice hulls as one of the raw materials. The output of this facility would be used in [another facility] where the remainder of the rice hulls would be bonded into architectural board using sodium silicate as binder.

Operational economy would accrue from the reduction of raw material input to a few basic materials, chiefly rice hulls and sodium carbonate, as well as from the savings in packaging, shipping, and sales cost of sodium silicate which would be manufactured in the captive facility. In addition, the plant would be flexible since it would produce two independently salable products." (48)

Although such industries may be somewhat large, capital-intensive and complex, they could have their place as rural industries evolve in some areas.

Rice husk cellulose, in addition to providing insulation materials because of its low thermal conductivity, has been found useful in reducing the costs of athletic equipment:

"Another delegate [to the Second International Olympic Course for Overseas Sports Administrators] from the Dominican Republic found that with canvas and rice husks, his team could make judo mats, saving £675 (U.S. $1280) on each mat." (100)

Southeast Asia Technology, Ltd. (SEATEC) in Bangkok investigated the use of coconut husks and burned rice hulls as primary and secondary filter materials respectively for water systems in various areas of southeast Asia. By using such free or cheap local filter materials, it was felt that expensive, not always available, imported or manufactured filter materials or sand could be done away with or reduced significantly. Trials run in four rural villages showed that, under normal circumstances, no coagulant was needed -- as was the case with sand or imported filter materials -- and, in abnormal instances, only small amounts of a coagulant were needed. Water from these systems met World Health Organization (WHO) standards and lowered operational and maintenance costs and down-time of the water supplies. The report pointed out that research is still needed into individual family-size jar filters and into why and how these materials perform so that a proper system to positively achieve desired results can be designed. The effluent quality obtained by using these filters is comparable to that obtained from the best slow sand filter prior to disinfection.* It was also found that the burned rice husks performed similarly to activated charcoal. (101)

Information concerning the active carbon quality of the burned rice hulls is not available at present, but research at the Indian CSIR Regional Research Laboratory in Hyderabad has shown that acceptable, commercially competitive, activated charcoal can be produced from the hard shell of the coconut. (102) This process will be discussed in the section on coconut wastes.

3.2.1.2 Rice Straw

While rice straw serves important purposes as bedding for animals, thatching, fuel, and fodder, it can be processed into other useful and more durable products. Throughout history, the most common use of rice straw for such products has been the addition of the straw** to clay in brickmaking to improve the quality of the bricks.

The process described in Section 3.2.2 for the manufacture of bonded, oriented, bagasse fiberboard (BOB) has been adapted to rice straw through a research project conducted by the University of Washington's College of Forest Resources and a California rice grower. Such rice straw boards, with preservative treatment and protective

*Disinfection by chlorination was not used during the tests so that the taste of the water would not be affected.

**Other straws have been used as well.

coatings, can be produced for (1978) \$0.15/sq. ft. (\$1.62/sq.m.) plus profit, overhead, transport, etc. "In any event, there appears to be sufficient margin ... to make the product for less than 25¢ per square foot [\$2.69/sq.m.] and still have a margin for profit." (103)

3.2.2 Coconut Wastes

Coconut as a crop has contributed at one time or another every bit of its fruit and fiber to man's welfare, and presently contributes to the livelihood of over 20 million families. (71) The coconut, in the languages of many of the areas in which it grows, is known as the "tree of life." However, in industrialized societies, the only products which have earned income are the meat of the fruit (copra) and the oil from this meat.

The primary "waste" from the coconut is the fibers of the husk (coir) which surrounds the kernel holding the meat. Husk fibers are about 15 to 35 centimeters (6" to 14") long, and consist mainly of lignin and cellulose, along with approximately 10% pectins, tannins, and water soluble and insoluble substances. (48) The fibers are embedded at the top of the nut in a "soft core-like ground tissue" (48) called pith, which contains the same ingredients as the fibers (in different proportions) along with hemicelluloses.
Both the husk fibers and the pith are chemically active, the pith more than the fibers, primarily because of the hemicelluloses.

Research at the Central Building Research Institute in Roorkee has shown that particleboards made of chipped coconut husks without the pith removed need little or no resin additive. The most resin shown to be needed was 0.5 percent as compared to 8 to 10% in ordinary wood boards.* The pith contains reactive ingredients which undergo chemical change during the board pressing process and impart sufficient bond strength. (104) CBRI has developed a machine which chips the husks without separation of the pith and which can be fabricated with locally available parts by village blacksmith, machine, or welding shops. The machine can process 600 Kg (1325 lbs.) of husks per day with a 5 HP power supply, and can be fabricated for an estimated (1978) $700. (102, 104)

Further research has shown that the cost of particleboards made from coconut husks could fall between 55 and 60% of the cost of ordinary wood particleboards. (48) Additionally, coconut husk particleboards are moderately resistant to termites and fungi. (48) Fire resistant boards have been developed at the CBRI from coconut pith and banana stems. Based on the CBRI laboratory scale system, a production scale plant could be constructed for an estimated (1976) cost of 33,000 rupees (U.S. $4,200) for a capacity of 50 sq. meters (538 sq. ft.) of board per day. (8)

Corrugated roofing sheets can be made from coir waste in a process developed at CBRI. The process consists of soaking the fiber in mineralized water for two hours, followed by draining and then mixing with dry cement. This mix is then made into a mat of the required thickness and slid onto a corrugated mold where it is held under pressure for four to eight hours. After removal from the mold, the sheet is then cured and dried. The process needs neither heavy machinery or high capital; the corrugated molds are the only special

*Because of the significant foreign exchange costs of resins and other adhesives, they are dealt with separately later in this chapter.

equipment. After a special coating is applied, the sheets perform comparably to conventional sheets, are 50% cheaper than asbestos cement sheets, and provide good thermal insulation. (48, 105) Production of similar panels is being investigated in a project which started in July, 1978, under the sponsorship of the Swedish Agency for Research Cooperation with Developing Countries (SAREC) and the Sri Lanka Building Research Institute and Coconut Marketing Board. (106)

Coir pith is extracted traditionally by retting (rotting) the husks for varying periods of time, ranging from two months to a year. The length of the retting process depends upon the salinity and temperature of the water used. (107) This pith has good thermal insulation qualities, and can be used as a filler in sandwich panels (48) or as an additive to cement. (108) When adding the pith to cement, a lightweight concrete is formed which, however, exhibits relatively high drying shrinkage (0.57%) when mixed and laid in-situ, resulting in small cracks. A plant which could produce 20 sq. meters (215 sq. ft.) of cement per day has been estimated (1976) to cost 20,000 rupees (U.S. $2,500). (8)

Retted coconut pith has also been developed into an expansion joint filler at CBRI (8, 48, 78) for use between concrete slabs in roofs, roads, runways, etc. The technology consists of drying the pith, mixing it with cashew nut shell liquid resin, forming the mix into a mat, pressing it, and finishing by cutting, etc. The material is resistant to termite attack and fungal decay.

Coconut coir pith can also provide about half of the ingredients in gaskets for automobile and other engines. The Indian National

Chemical Labs at Poona have developed a technology to produce rubberized coir-pith sheets for an estimated (1976) cost of 133,000 rupees (U.S. $15,250) for a capacity of 5.32 tons per annum. (8) The process involves mixing the pith with nitrile and other rubbers, followed by vulcanizing the mix under pressure and temperature in suitable molds. The product-to-residue ratio is 5.7:3. (6) The process has been licensed and is in production in India. (102)

An interesting product from the water in the coconut may develop because the fluid taken directly from seven-month old nuts has been successfully used in emergency situations as a substitute for parenteral solution. The composition of the water has been found to be close to isotonic glucose serum, (109) or what is known as D5W (a 5% solution of dextrose in water). The water contains 95.5 percent water, 4% sugar, and minerals, proteins, fats and iron. (107)

As with the wastes from rice hulls, coconut wastes can also be used in combination with cement and soil or sand to produce lightweight building blocks. (95)

At present, few commercial scale processes have been developed which use the coconut's shell because an efficient chipper has not been developed and because of the lack of inexpensive adhesives. (48) However, research conducted in the U.S. during the mid-1940s has shown that coconut shell dust can be used as a filler in plastic moldings, giving them a smooth and lustrous finish while improving heat and moisture resistance over other organic fillers. Additionally, because of high (33%) lignin content and low resin absorption rate, less resin should be required. (107, 110)

Coconut shells have also been used as the primary raw material in the production of active carbons of gas-absorbent grade. The process, developed by the Indian CSIR Regional Research Lab at Hyderabad, consists of crushing the shell to the required size, treating it with zinc chloride and activiting it in a rotary kiln. The activated material is then washed, dried, and packed. The amount of investment required to produce a ton of active carbon per day, on a three shift basis, is high however: $280,000 (1978), including working capital. (102)

The remainder of the coconut tree, once it is past its bearing stage, is a nuisance in many instances, and frequently villagers simply put it out of their way because there is no immediate traditional need for it. The Ministry of Forests, Fiji, at its research station at Nasinu, near the capital of Suva, has been investigating the economics of producing sawn timber from these coconut logs. In August of 1978, they started the construction of an all-coconut house (except for the roofing, footing, window glass, plumbing, and wiring) in order to gauge the wear and strain characteristics of the hard coconut wood. (111) A similar house has been built in the Philippines. (71)

3.2.3 Sugarcane Wastes

Sugarcane is one of the largest non-cereal food crops grown in the world, with over 10.3 million hectares (25 million acres) planted annually (112) in tropical areas. Bagasse, the fibrous residue of the cane stalks left after milling, is the primary (28-36% of cane) waste product of sugar production from cane. While much of the bagasse is used as a fuel for the milling process (112) -- some mills obtain eighty percent of their energy needs from bagasse (113) -- processes have been developed which employ bagasse in the production of roofing panels, paper (see Section 3.2.6) and boards. It has been estimated (75) that up to 50% of bagasse produced can be used for alternatives other than fuel because present technologies should not require much more than half the bagasse for process energy. Bagasse's low density (10 lb/ft^3; 160 Kg/m^3) and flammability make it a bulky, costly, material to handle, store, or transport, and it is liable to deterioration by rot or fermentation* unless processed or dried and treated shortly after it comes from the mill. Suitably stored bagasse, after depithing, yields a fiber comparable in pulping quality with that of fresh bagasse. (112) While the ash from bagasse is reported to have pozzolanic properties (114), research into technologies to maximize the pozzolana production does not seem to have reached the same levels as has been done with rice hulls by Mehta, Cook, the Indian CBRI, and others (see Section 3.2.1.1).

Research conducted between 1973 and 1977 by Monsanto Research Corporation (MRC) in collaboration with Washington University's Center for Development Technology (CDT) and the College of Forest Resources of the University of Washington, under a grant from AID, developed four different composite roofing panel systems which utilize major percentages of bagasse as a filler, and minor amounts of phenolic or other resin binder. (115, 116) This project was started

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*One microorganism which causes bagasse to deteriorate, Thermoactinomyces sacchari, also causes bagassosis, an acute pulmonary illness which can appear after a few weeks exposure to heavy concentrations of bagasse dust. (112)

in MRC's Dayton Lab and then expanded with experimental work done in cooperating institutions' facilities in Jamaica, Ghana, and the Philippines so that developing country personnel participated in the development, and shared the knowledge, of the processes. The four products developed differ in the type of binder and/or manufacturing process, but use in common bagasse filler, an intensive mixing process, and a compression molding press. All four can be produced as flat or corrugated panels for roofing or other applications, both structural and non-structural.

The four processes and products developed are:

1. Bagasse-Reinforced Phenolic (BRP) composite roofing "is a rigid, strong, durable, red pigmented panel product. The process involves only 'fibrillating' of the bagasse, dry blending with resin binder, and molding-cure in 3-7 minutes at 275°F [135°C]. The raw material cost is projected to be ~ 12¢/ft^2 [$1.29 per square meter] at 30% powdered phenolic resin." (115) Sales prices are projected to be 3 to 4 times the raw material cost.*

2. Bagasse-Reinforced Hard Rubber (BRR) composite roofing "is a medium modulus, strong, durable, red pigmented ... panel product. In the process, the bagasse filler, pigments, curing agents, etc. are compounded in a Banbury mixer. The rubber compound is formed into continuous sheets ... These flexible sheets are molded and cured for 30 minutes at 325°F [163°C] to a rigid state. Raw material cost is 7-9¢ per square foot [75-97¢ per square meter] using the lowest cost grades of natural rubber." (115) Sales prices are projected to be 3 to 4 times the raw materials cost.

3. Bagasse-Reinforced Thermoplastic (BRT) composite roofing "is a rigid, strong, durable, red-pigmented ... panel product. In the process the bagasse filler, pigments, etc. are compounded together in a Banbury mixer. The compound is formed into continuous sheets [which] are molded and rigidized by cooling. Raw material costs

*These costs can be compared to the costs for the major commercial competitor, corrugated metal roofing, of around $3.00 per square meter ($0.28/ft^2). (106)

are projected to be about 14¢ per square foot [$1.51 per square meter]." (115) Sales prices are projected to be 3 to 4 times the raw materials cost.

4. Phenolic-Bonded, Oriented Bagasse Fiber (BOB) composite roofing "is a durable, buff-colored ... panel having directional strength properties. As currently formulated, this product has the most bagasse filler and least resin binder. The process requires different equipment and more steps than the others. The bagasse is 'wet' depithed, and phenolic resin is precipitated onto it. The fibers are oriented in a centrifugal water extractor, and the fiber mat is compression molded and cured. Raw material costs range from 6-11¢ per square foot [65¢-$1.18 per square meter] for 0.1 in. [.254 cm] thick corrugated panels." (115) Sales prices are projected to be four to five times the raw material costs.

Foreign-exchange cost requirements were estimated to account for the following percentages of projected sales prices: a) BRP-25%; b) BRR-15 to 17%; c) BRT-33%; and d) BOB-15 to 19%. Slight changes in some of the processes enables the production of non-structural wall panels for even lower costs.

The major drawbacks to these products/processes are their intermediate to high capital requirements -- $100,000 and more for businesses already involved in some aspect of the process (103), and the undesirability, because of chemicals leaching from the roofing, of roof water collection systems using these roofs. This latter drawback is important to rural areas where roof catchment systems secure water at the dwelling; in areas with piped water supplies this is less important. Special coatings may, at a cost, ameliorate this problem. While the lower-cost products from each process do not contain fire retardants, according to the Monsanto authors, "none of the ... roofing materials present as great a fire hazard as the asphalt shingles most commonly used for roofing in the U.S. and other developed countries." (115)

Sugar mill press mud is a waste by-product from sugarcane milling and amounts to between 6 to 8% of the weight of sugarcane milled. Both sulphitation and carbonation milling processes produce this "mill mud." From the sulphitation process mills the mud has prime use as a fertilizer, but from carbonation process mills the mud, primarily calcium carbonate (a lime sludge)* is usually thrown out, frequently at high cost. (48, 117) However, researchers in Nepal and India have found that carbonation mud can also be useful.

In India, a process has been developed to "refine" the mud: that is, remove the lime from the mud. The process requires high pressure (6,000 psi) compression of the mud into briquettes which are then fed into mixed-feed kilns and fired at 950°C - 1000°C (1742°F-1832°F). The briquettes are then ground in a ball mill, giving a powdered lime for (1976) 47.48 rupees ($6) per metric ton. (48) In some instances the waste sludge is pure enough for more direct use, as the following process descriptions show.

In Kathmandu, researchers at Tribuvan University have developed a process for obtaining a low-cost cement substitute or building lime from the carbonation process mud. The product is made by mixing the dry mud with a sawdust fuel; the mix is then burned in a controlled furnace at less than 900°C (1652°F). (118) The Central Building Research Institute of India has developed a masonry cement made by the intergrinding of the waste sludge with portland cement.

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*Similar calcium carbonate sludges are by-products of sulphate and soda process paper mills, tanneries, and calcium carbide based acetylene industries.

This masonry cement, owing to the high surface area and porosity of precipitated calcium carbonate sludges, possesses good workability and water retention properties without the air entraining agents required for portland cement-limestone or slag blends. Additionally, the intergrinding costs are substantially lower when lime sludge is used.

The CBRI process requires $30,000 (1978) worth of fixed capital for a plant with a capacity of 4,800 tons a year. It is estimated that the product prices from this process will be 30% cheaper than other cements. (102) Cost estimates were not available during this study for the Tribuvan University process.

With the increasing need to conserve energy, insulation materials have received considerable attention. However, the study was unable to locate any examples of current production of mineral wool from carbonation process sugar mill press mud. In 1952, researchers at the Shri Ram Institute for Industrial Research developed a process for the production of a sound and heat insulating mineral wool from this mud. At that time, the capital requirements for an unspecified size plant were high (1952 U.S. $45,000), and the product's cost was 1952 U.S. $0.005 a pound. (117) If current technology can improve this process' relative costs, a good source of non-combustible insulation will be available in those areas of the world where little is now available.

3.2.4 Cassava

Cassava, also known as manioc and tapioca,* is a tuberous shrub, originally native to Latin America. It is now grown throughout the humid tropics, with over 17 million acres (42 million hectares) planted worldwide (119). It is the staple food of the poorer sections of the populations in many developing countries, especially so in areas of Latin America and Tropical Africa, and it is an important secondary food in all the areas in which it is grown. Starch production from cassava tubers is a common cottage industry in many countries because the starch pellets or flour will keep for extended periods; additionally, the starch products are frequently considered as more palatable than the tubers. The starch has also been used to replace sago starch as a sizing and finishing material in the textile industry. (119)

In 1972, the Technology Consultancy Center (TCC) of the University of Science and Technology in Kumasi, Ghana, developed a paper glue made from cassava starch and alkali from plantain peels. The pilot plant they helped developed produced 50 U.S. gallons (190 liters) a day, employed over 25 rural dwellers and supplied virtually all of Ghana's need for glue. This project required about $5,000 for plant and machinery, and in relying upon local supplies of raw material, it facilitated the rapid and easy horizontal transfer of technology as well as a relatively high profitability: the annual turnover per worker was equal to the total investment in the plant

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*Tapioca usually is used only in reference to the starch prepared from the plant; however in some areas the terms are used interchangeably. (119, 120) and machinery. In late 1972, the finished product sold for 63 per-cent of the imported competition's retail price; after two years of production, imports were restricted. (121, 122)

Cassava starch can also be mixed with certain other plant alkalis to make plain laundry starch. In fact, the Ghanaian entre-preneur involved in the first production in Ghana of glue from cassava starch had been making laundry starch. He sought assistance from the TCC in the development of the glue as a means of product diversification. (122)

3.2.5 Animal Wastes

Leather residues -- vegetable-tanned shavings and trimmings -- can be made into boards for the manufacture of insoles, etc. in the footwear industry. India's Central Leather Research Institute has developed and patented a process which consists of the following steps: dry grinding of any vegetable-tanned scraps, mixing with binders in a Hollander mixer, then wet grinding in a Hollander beater; this pulp is then fed into a forming unit and pressed, followed by calendaring (rolling) and trimming. The minimum suggested economic plant would require an estimated investment, including working capital, of (1978) $90,000, and produce 1,000 boards 7.5 cm x 5 cm x 2.0 to 2.5 mm (3" x 2" x 1/12" to 1/10") per day. (102)

The Australian Leather Research Group of the Commonwealth Scientific and Industrial Research Organization (CSIRO) has developed acoustical tiles which are made from leather residues. Their pilot stage process consists of grinding the leather, mixing it with a PVA resin, pressing the mix and then letting it dry. Using this process, 2.6 Kg (8 lb) of leather waste can make a tile approximately

53 cm x 41 cm (21" x 16"). (6) Cost estimates are unavailable at present. Press boards can also be made from the manure of cattle, according to reports of work being done in the U.S. (6), but no details have been obtained.

3.2.6 Paper

The principal raw materials used in paper manufacture are cellulose pulp, fillers, sizing materials, and dyes. The cellulosic raw materials used for pulp production are selected by the physical characteristics of their fibers: the length of the fiber, the ratio of the fiber's length to its diameter, the fiber's flexibility, etc. The length, the length/diameter ratio, and the fiber wall thickness influence the paper's tear resistance; the higher a fiber's flexibility, the denser, stronger, and better folding the paper. (75)

Paper manufacture involves three principal steps: pulping the raw material, refining the pulp, and paper making and finishing. Conventional paper technology's sophistication has advanced to the point where it is thought to have practically nothing to offer in the way of solving the specific problems of developing countries. (74, 114)

> "The size and sophistication of conventional paper making machines have grown in response to the pulp yield of the conventional 'modern' pulp mills. The need for mass scale production as a way of survival in international paper trade has more or less compelled the paper production technology to add on to the size and speed of paper machines. Over the past several decades, the paper machine has increased in width from 2 metres to around 10 metres and the operating speeds have increased from about 100 metres/minute to 900 metres/minute. In terms of annual production capacity, the single machine has moved from approximately 500 tonnes/annum to upward of 150,000 tonnes/annum. As a result, paper production based on conventional processes

> has become prohibitive for developing countries in terms of both the production in relation to domestic market and cost." (74)

According to the Draft Report of the Working Group on Appropriate Technology for Paper Products and Small Pulp Mills (a part of UNIDO's Forum on Appropriate Industrial Technology, held in New Delhi/Anand, India, from 20 to 30 November, 1978) (114), conventional technologies, based almost entirely on wood (softwood) fiber and producing highly bleached and sophisticated products cannot provide satisfactory answers for the technological requirements for the use of non-wood fibers. Wood-fiber resources of developing countries are mainly tropical hardwoods which are difficult to exploit without considerable infrastructure and highly capital-intensive equipment. "The strategy for development of paper industry in developing countries should, therefore, be based primarily on utilization of alternative non-wood fiber resources on an appropriate scale." (74)

Successful operation of small plants, up to 20-25 tons per day capacities, and using "unconventional" fibers like paddy straw, reeds, bagasse, etc. is occurring in Brazil, Egypt, and India. (74) Even in the United States, while today there are none, there were some 50 pulp mills in 1950 producing 650,000 tons of pulp annually from wheat straw. (3) The discussion paper prepared by UNIDO for its 1978 Forum on Industrial Technology (74) noted that:

> "By and large, it might be advisable for the developing countries to concentrate on alternative raw materials such as wastes from associated timber or agricultural industries and alternative fibre sources like reeds, bamboo, straw."

Because the pulp from such residues is composed of short fibers, to improve its runability during production and to obtain the required strength properties for lightweight writing and printing paper, it will need to be mixed with long-fiber pulp. There are a few agricultural crops that can provide the long-fiber pulp for DCs, such as banana and abaca stems, jute, sisal, and hemp.* In India, where wood has not been used to any large extent other than for newsprint, paper is manufactured from bamboo (*Bambusa arundinacea* and *Dendrocalamus strictus*) and sabai grass, supplemented with rags, depithed bagasse, hemp rope, jute waste, hessian cuttings, and waste paper. (75)

The methods employed in pulping non-woody materials for paper are: lime process, soda process, sulphate process, neutral sodium sulphite process, caustic soda-chlorine process, and mechanical-chemical process. Processes using soda and batch digesters have been found effective for small-scale pulping of non-woody fibers, and may be pertinent to the needs of DCs because of their simplicity, low-capital requirement, and sulphur free cooking. In addition, the use of batch digesters gives the flexibility to use different types of raw materials which require different processing temperatures, soda solutions, etc. The technical and economic limitations of the known small-scale processes are related to the lack of a process for recovering the cooking chemicals, which means that the "black liquor" which can contain up to half of the raw material feed and all of the chemicals has to be discarded. (74, 75)

**Cannabis*, ssp., although outlawed, is another good source of long fibers. (123)

In India, under the impetus of the All India Khadi* and Village Industries Commission, and through research at the CSIR Regional Research Laboratory at Hyderabad, satisfactory processes for the hand manufacture of paper have been developed using natural fibers, rags, and agro-wastes. (75)

The director of the Technology Consultancy Center, Kumasi, Ghana, in a tour of the Indian Subcontinent in late 1977, observed a process in Kathmandu, Nepal, and Lucknow, India, for making paper by hand from cotton wastes and tree bark. The material, primarily cotton wastes, was broken up and then soaked in a digester and run over a roller to make a slurry. The slurry was removed by sieve and placed in a stack between cloths, then pressed, dried, and cut. The paper produced was thick, but inconsistently so, and used for file covers and documents. Kaolin could be added to obtain a glossy surface. (118)

Anthony Hopkinson, of Hertfordshire, England, in a March 1977, conference in Caracas, Venezuela, sponsored by the U.S. National Academy of Sciences (NAS), presented a paper-making machine he has spearheaded development of, which costs only (1977) $2,400. Some parts of the machine are capable of being produced in most developing countries. Although developed as a way of reusing waste paper, the machine can handle other pulps, such as the agro-wastes mentioned earlier. (123)

3.2.7 Resins, Binders, and Adhesive Extenders

Resin or other adhesives are seen as the central problem in the wider use of cellulosic agricultural waste composites, be they boards,

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*Khadi, or khaddar, is an Indian term applied to the cotton, woolen, and silk textiles woven on handlooms from hand-spun yarn.

blocks, panels, or furniture, according to the Materials Science Panel of the Science Committee of NATO,* (40) and other bodies. Before the massive post-war growth of the petrochemical industry and the extensive development of synthetic resins for binders, considerable work had been done on natural binders produced from agricultural waste products. A number of patents were issued for processes to extract lignin and furfural, two sources of natural adhesives. (124) With these now in the public domain, and with cost and availability constraining the use of petroleum-based resins, there would appear to be good reason to re-direct this early effort to the material needs of developing areas, were there are often ready supplies of timber and agricultural wastes.

The Indian Plywood Industries Research Institute (IPIRI) in Bangalore has been working over the years to develop alternative resins/adhesives or extenders for currently used resins/adhesives. To date they have produced adhesive extenders from coffee seed meal, sal meal, groundnut cake, soya meal, and tamarind seed. (6, 8, 78) The tamarind seed itself has binding qualities, and when ground to a powder can replace 20-60%; by weight, of synthetic or tannin adhesives.

IPIRI has developed a pure adhesive from cashew nut shell liquid. (6) The adhesive contains 75-100% condensed cashew nut shell liquid, depending upon the product (plywood, particleboard) and its use. Some products require the addition of phenol and formalin hardeners.

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*This panel proposed a meeting for the late summer, 1979, to address this subject. (40)

Also, the CBRI has developed a process which uses cashew nut shell liquid to produce a sealant for joints and cracks in buildings, and a water- and weather-proofing compound. This process is estimated (1976) to cost 25,000 rupees (U.S. $3,200) for a 100 Kg (220 lbs.) per day capacity output. (8)

CBRI has also investigated the use of cement as a binder in producing wood-wool type fiberboards, particleboards, blocks, etc. As mentioned earlier, boards can be made with cement as a binder from rice husks and coconut pith; additionally, groundnut husk and wood chips have also been found not to exhibit inhibitory action on strength development in the cement. Panels of adequate strength are obtained when mixed in a ratio of 1:2 by weight and pressed to a density of 1100-1200 Kg/m^3 (69 lb/cu. ft.). (125)

3.2.8 Non-Waste Plant Fiber Materials

Vegetable fibers, both hard (sisal, henequen, abaca*, etc.) and soft (cotton, jute, flax**, etc.), are among the oldest plant raw materials processed by man. Within the last few decades however these raw materials have lost much of their historical preeminence to synthetic, petrochemical substitutes. (126, 127, 128) Because so much of these raw materials is produced for limited use-markets (e.g., 75% of the commercial hard fibers is used for cordage (126), and the soft fibers are used primarily for fabrics and cordage (127, 128)), producers are frequently subjected to wide price fluctuations as well. It is thought that by diversifying the end-product uses for

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*Also called manila or manila hemp.

**Flax seed is called linseed.

these fibers that some isolation from these two elements would be achieved. (48, 126)

Many natural fibers have been found to produce satisfactory paper pulp. (75) Others hold promise as raw materials for small-scale board and panel manufacture (38, 48, 49) because of their physical properties and because they can be oriented manually as well as mechanically. In addition, natural fibers present, after 20 years of industrial experience (48) no outstanding problems of transport or storage. As many natural fibers, especially those in the same type-group (hard or soft), can be substituted for each other to some extent, potential processes which use them should be less affected by problems of supply (see Section 4.5.3).

3.2.8.1 Sisal Fiber Reinforced Concrete Panels

Sisal (Agave Sisalana), a plant native to Central America, is now grown all over the world, with most production occurring in East Africa and Indonesia. (106) The main product of sisal for world markets is twine. (126) Although sisal markets have received considerable competition from synthetic fibers, increasing oil and related energy resources costs may slow down the growth of synthetics' share of the market. Additionally, the processing of sisal requires little energy. The competition from synthetics has kept prices for sisal relatively low, and motivated growers to look for new ways of using the fibers.

The Swedish Agency for Research Cooperation with Developing Countries (SAREC) funded a research project, conducted by the Tanzanian Building Research Unit and two Swedish institutions, into the possibility of producing sisal fiber reinforced concrete roofing and wall panels. The production process developed in 1977 and 1978 by the project can be adapted to varying levels of mechanization. Starting in 1979, the project will involve the Tanzanian Small Industry Development Organization, and will focus on small-scale production to develop methods, equipment, etc. and make transport and market surveys. Figure 3.4 shows the process steps in their most basic, labor-intensive form. Figures 3.5 and 3.6 portray small-and intermediate-scale industrial processes. The cost of the materials for the finished product (in sisal fiber producing areas) is estimated at (1978) $\$0.90/m^2$ ($0.084/sq. ft.), and the estimated investment and labor costs will no more than double this amount; corrugated steel roofing, the preferred product in many DCs (11, 106), costs over $\$3.00/m^2$ ($0.28/sq. ft.), cannot be walked on much without damage, and provides no insulation. (106)

3.2.9 Banana Wastes

When the fruit of the banana tree is cut off, most of the rest of the plant is discarded, even though much of the tree contains fiber usable for making ropes, mats, etc. (129) Researchers in Sri Lanka and India have developed simple methods for extracting the fiber from the leaf sheaths (see Figure 3.7). (130)

The fiber contained in the sheaths is concentrated in the outer surfaces, and is removed simply by peeling off strips from the outer part of the sheaths using a knife to start. The peeled-off strips have the remaining flesh and skin removed by scraping with a blunt knife, but this is a slow process, yielding a little over an ounce (30g)

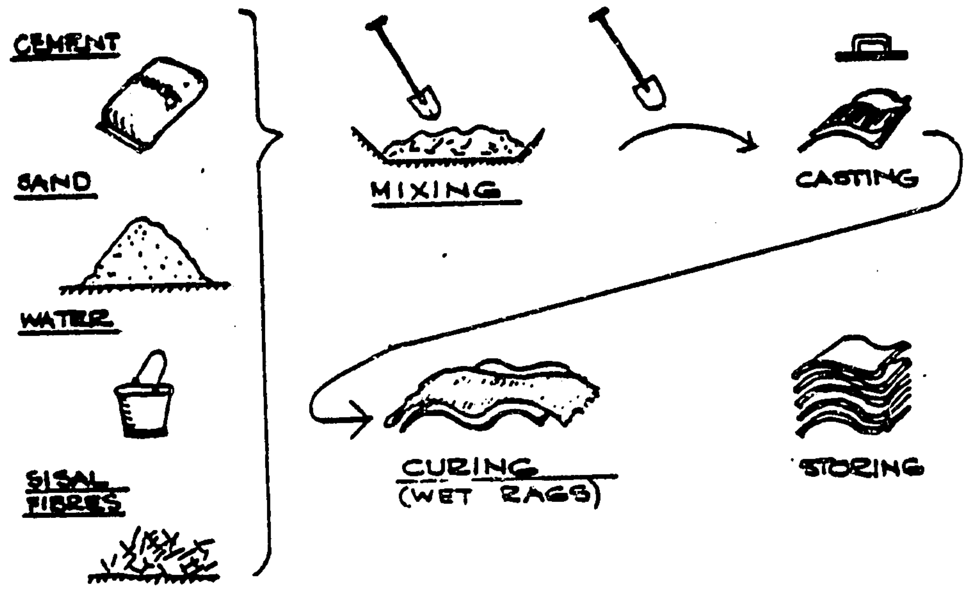

Figure 3.4 Idea of Production of Sisal Fiber Reinforced Concrete Panels on the Village Leve' When Chopped Fibers Are Used

Source: Reference (106).

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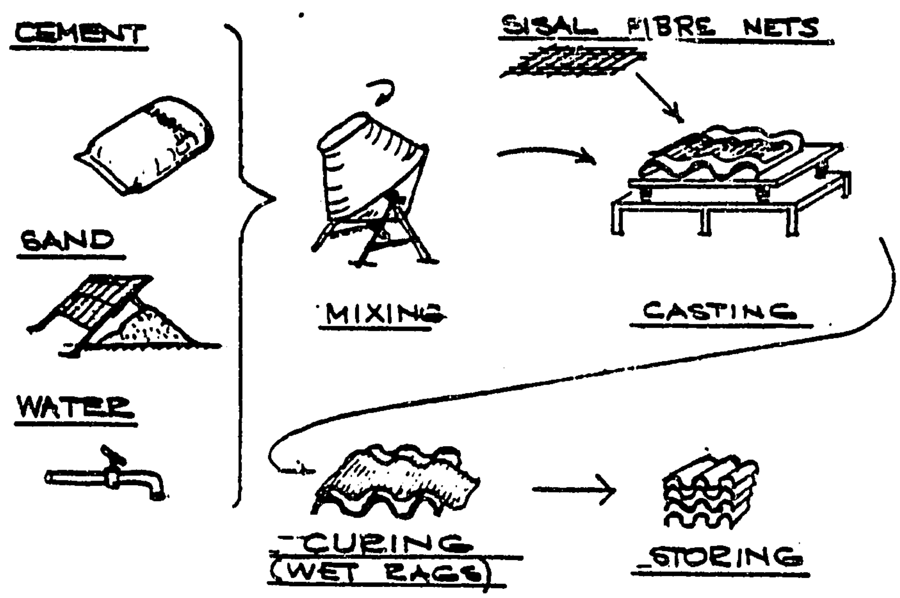

Figure 3.5 Idea of Production of Sisal Fiber Reinforced Concrete Panels in Small-Scale Industries Using Fiber Nets

Source: Reference (106).

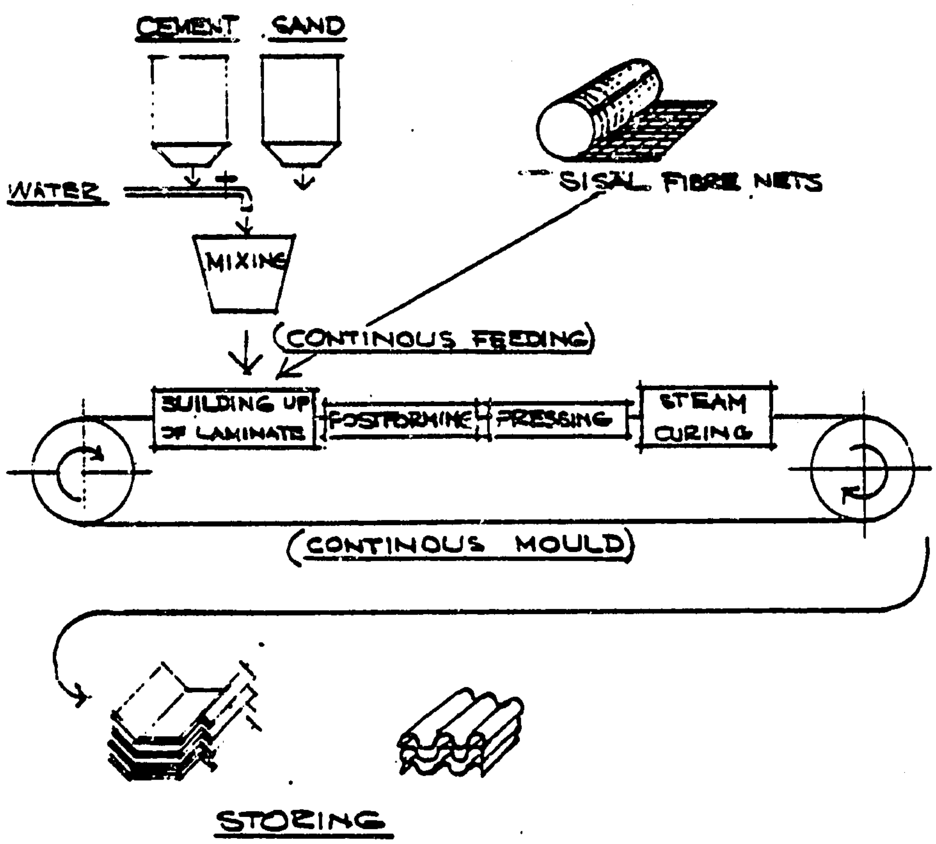

Figure 3.6 Idea of Production of Sisal Fiber Reinforced Concrete Panels in Mechanized Industries

Source: Reference (106).

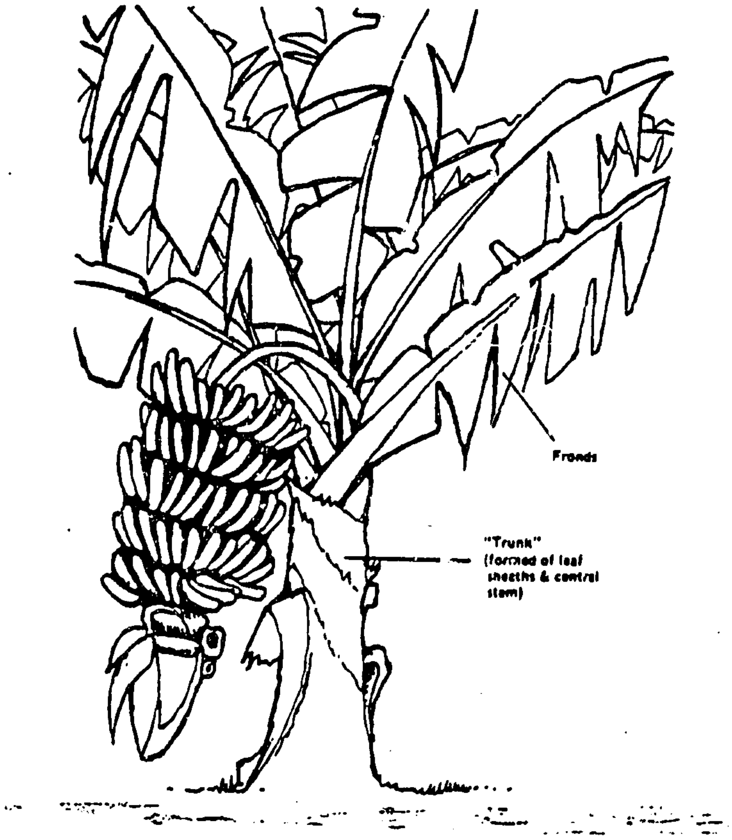

Figure 3.7 The Banana Tree

Source: Reference (130)

of fiber in two hours. India's Khadi and Village Industries Commission has developed and introduced machines consisting of a rotating drum with blades which scrape away the skin and flesh, leaving just fibers. Although the fiber is weakened by such harsh treatment, and not as well cleaned as that obtained by hand, output is increased to about eleven pounds (5 Kg) in two hours. In Sri Lanka the hand method has been made easier by developing a simple pressing operation to remove the soft inner material. After separation, the fibers are washed and dried to prevent discoloration and brittleness. The finished fiber can be spun and woven, used like sisal in making fiber reinforced cement sheets (see Section 3.2.8.1) (130), or used in paper production. (74)

A paint material readily and easily made from banana stalks and leaves has been used in Ghana as a waterproofing agent for several building materials, including soil-cement blocks which ordinarily deteriorate rapidly in moist climates like Ghana's. The manufacture of this material is accomplished by cutting the stalks and leaves into very small pieces and placing them in a 55 gallon (208 liter) drum, until the drum is two thirds full. The drum is then filled with water and the mixture brought to a boil; while it is boiling, the ingredients are mashed from time to time until the liquid begins to thicken. After thickening, the heavy material is screened out, and the mixture is ready to be brushed onto walls. Depending upon climatic and use conditions (surface, material, exposure), repainting is required at between one and three year intervals. (48)

3.2.10 Panels and Board from Agricultural Wastes

Research to date has indicated that it is, in principle, possible to manufacture agglomerated boards or panels from almost all agricultural residues and fibrous raw materials. (6, 38, 48, 79, 131) Unfortunately, the properties of boards from many of these resources are unfavorable, and satisfactory properties are frequently obtained through the use of large amounts of binder. (38) However, it is not clear from the literature whether the residues tested for board making had been subjected to any preprocessing technique to eliminate deleterious or harmful constituents, if any, of those residues. Nor is it clear from the literature how many varieties of a given species were tested.

Table 3.3 contains a checklist of the more viable raw materials for board production. Flax, hemp shives, bagasse, and cereal straws have been used for the commercial production of 579,000 metric tons of particleboard annually in parts of Europe, although production there has diminished because of an insufficient raw material supply. (7, 30) The other product technologies may also be designed for similar scales of production, although the smallest production scale in recent (1970) use, according to the FAO (132), is 1,500 metric tons annually. Details of many of the processes in the table were not available to this study.

In addition to the board making processes mentioned in the crop-specific sections earlier in this chapter, one process which is not residue-specific was noted. The Indian CSIR Regional Research Laboratory in Jorhat has developed a simple process for the production

Table 3.3

Selected Check-List of Agricultural Residues Tested for Board-Making (Technology Scale Is Disregarded)

Raw Material	Insulation Board	Hard-board	Particle-board	Fiber-board	Other	Notes
Abaca (Manila)			E*			
Areca nut husk	E	E				
Bagasse	E, I	E, I	E, I	I	E - Plasterboards	Refs. 6, 102
Bamboo	E	E, I	E	E, I	E - Plywood E - Concrete Panel Reinforcement	Refs. 74, 130
Banana		E		E		Ref. 6
Cashew nut shell		E	E			
Cassava stalk	E	E	E			
Cereal Straw	E, I	E, I		I		
Coffee Husk			E			
Coir-dust	E	E, I				Ref. 6
-fiber & husk	E, I	E, I	E		E - Concrete Panel Reinforcement	Refs. 6, 102, 104
Cotton-husk			E			
- stalk			E, I			

*"E" indicates that the material has been the subject of laboratory experimental work only. "P" indicates pilot plant stage. "I" indicates that the material has been, or is being, used industrially. Adapted from reference (11), additional references used are cited in "Notes" column.

Table 3.3 (continued)

Selected Check-List of Agricultural Residues Tested for Board-Making (Technology Scale Is Disregarded)

Raw Materi Raw Material	Insulation Board	Hard-board	Particle-board	Fiber-board	Other	Notes
Esparto			E			
Flax and Linseed Residues	E	E	I	E		
Groundnut (peanut) shell			E, I			Ref. 102
Hemp	I	I	I	E, I		Ref. 75
Jute		E, I	E, I	I	E - Asphalted Roofing	Refs. 6, 75
Kenaf		E	E			Ref. 6
Maize (corn) cob		E	E		E - Plywood	Ref. 6
Mustard stalk		E				
Palm fronds, fruit stems (raffle)	E		E, I	E		Ref. 6
Papyrus	E, I	E, I				Production now ceased
Rice-husks	P		E	E	E - Cement Panel Aggregate	Refs. 6, 96, 98
- straw			P	E, P, I		Refs. 6, 74, 102, 104
Sisal		E			E - Concrete Panel Reinforcement	Ref. 106

of particleboards from rice husks, groundnut husks, coconut pith, bagasse, seeds, and grass, as well as sawmill residues, without the use of synthetic binders. The boards have acceptable tensile strengths and moduli of rupture.* Although a larger (50-100 ton per day) plant is thought to be more viable commercially, a 10 ton per day plant would require an investment of (1978) $200,000. (102)

3.3 SUMMARY OF REVIEW OF CURRENT TECHNOLOGIES

Listed in Table 3.4 are the residue-product technologies reviewed in the previous Section. As the Table shows, more than one type of residue can be used to produce a given product, much the same as Table 3.3 presented the many different residues that have been shown to be viable raw materials for board production. While this may indicate other residue-product interrelationships, it cannot be considered as more than an indication until R&D confirms each given residue-product (see Section 4.2.1). However, the variety of materials which can be produced with appropriate, light-capital, technologies from the small number of residues covered in the state-of-the-art review augurs well for the ability of agro-wastes/fibers to meet the variety of building materials needed in many developing countries. This is especially apparent when one considers that the R&D efforts to date reflect a wide range of thoroughness, from the quite detailed study of rice hulls' pozzolanic properties, to the rather superficial study of the waterproofing properties of banana stems, sheaves, and fronds.

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*Tensile strength parallel to plane of board: 75-100 Kg/cm^2 (485-645 psi). Modulus of rupture: 110-125 Kg/m^2 (3300-3700 psi).

Table 3.4

List of Residue Product Technologies Discussed in the State-of-the-Art Review

Residue	Product (References)
Banana stems, sheaths, etc.	Corrugated roofing panels (106, 130) Paint material (48) Paper (3, 74)
Cashew nut shell	Adhesive (6) Joint and crack sealant (8)
Cassava	Glue (121, 122) Starch (119, 122)
Coconut husks	Active carbon (102) Building blocks (95) Corrugated roofing panels (48, 105, 106) Expansion joint filler (8, 48, 78) Filler for plastics (107, 110) Gasket material (6, 8, 102) Lightweight concrete aggregate (8, 108) Panel filler (48) Particle boards (8, 48, 102, 104)
Cotton wastes	Paper (118)
Groundnut (peanut) husks	Panels, blocks, etc. (125)
Leather wastes	Acoustic panels (6) Boards (102)
Rice husks (unburned)	Boards (38, 48, 97-99) Building blocks (83, 94, 95) Filler for plastics (97) Insulation and padding (100) Lightweight concrete aggregate (48, 96)
Rice husks (burned)	Hydraulic cements or pozzolanas (6, 8, 48, 50, 78, 82, 84-92) Lightweight concrete aggregate (96) Rubber reinforcement (87) Sodium silicate (water-glass) (48) Water filtration medium (101)

Table 3.4 (continued)

List of Residue Product Technologies Discussed
in the State-of-the-Art Review

Residue	Product (References)
Rice straw	Fiberboards (103) Paper (74, 75)
Sisal fibers	Corrugated roofing panels (106) Paper (74, 75, 106)
Sugarcane bagasse	Boards (75) Corrugated roofing panels (103, 115, 116) Paper (74, 75, 112)
Sugarcane mill press mud	Lime (48, 117) Masonry cement (102, 118) Mineral wool (117)
Wheat straw	Paper (74)
Coffee seed meal Groundnut cake Sal meal Soya meal Tamarind seed	Adhesives and/or adhesive extenders (6, 8, 78)

4. RESEARCH AND DEVELOPMENT NEEDS AND INITIATIVES*

4.1 INTRODUCTION

This chapter reviews the needs for research and development into new materials and new and improved technologies in order to facilitate the continued use, and perhaps increase the use, of renewable agro-wastes and natural fibers for building and other materials. Specific initiatives suggested will be responsive to as many of the widely varying needs, reviewed in Chapter 2, of developing countries as possible, especially those which can meet the needs of both rural and urban DC societies. This approach is necessary even though the principal focus of this thesis has been towards rural needs and rural industrialization: The rapid rates of urban growth experienced in developing countries, which far surpass current material supply capabilities, together with the need to have a large potential market as an incentive for investment and involvement in agro-waste/natural fiber materials industries compel consideration of both sectors' needs.

As developed in the Principal Study (19), initiatives for the rural end of the rural-urban continuum will emphasize techniques which improve the properties of organic materials with a minimum of alteration to their physical form. For the urban end, emphasis will be on the development of materials which meet the stricter requirements

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*The author gratefully acknowledges the contributions of J. P. R. Falconer to this chapter, particularly for portions of Sections 4.1, 4.2.2, 4.3.1, 4.3.1.1, and 4.3.1.2, and Table 4.1. (53)

of urban areas and substitute for currently imported materials. These different emphases result from the different needs of each end of the continuum. In rural areas, traditional building forms, derived from generations of experience with familiar materials, are also the cheapest forms. In urban areas, higher concentrations of structures and people have exceeded the structural, durability, and/or safety properties of many traditional building forms. The initiatives summarized in Table 4.1 borrow heavily from the consensus developed during the Principal Study, but reflect conclusions drawn from the reviews done separately for this thesis.

4.2 NEW COMPOSITE MATERIALS

4.2.1 Plant Materials as Aggregates and Fillers

The basic concept of adding thin fibers to a material in order to improve its properties has been known for some time. Chopped straw and other fibrous matter have been added to clay walls for thousands of years. In recent times, linoleum, asbestos cement, reinforced concrete, reinforced rubber and fiberglass resin systems have assumed considerable importance. Although composites have been used as structural materials for many years, coordinated research and development in this field is quite recent and has occurred mostly during the past 15 to 20 years for defense and space applications in industrialized countries.

It might be possible to produce improved agro-waste/natural fiber building materials using such composite materials techniques. According to a 1969 report of the Center for Development Technology (CDT) of Washington University (52) the

Table 4.1

Research and Development Related Initiatives in Appropriate Technology for Building and Other Materials from Agricultural Wastes and Natural Fibers*

1. *SUPPORT NATIONAL AND INTERNATIONAL COLLABORATIVE EFFORTS TO ASSESS THE AVAILABILITY OF AGRICULTURAL BY-PRODUCTS AND WASTES AND THE POTENTIAL ALTERNATIVE USES TO WHICH THESE MATERIALS MIGHT BE PUT.*

   This effort should include planning, policy-study, and evaluation activities involving economic, social, political, cultural, and environmental as well as technological factors.

2. *SUPPORT THE ESTABLISHMENT OF CENTERS IN DEVELOPING COUNTRIES (NATIONAL/REGIONAL) TO FACILITATE THE COLLECTION, EVALUATION, AND DISSEMINATION OF INFORMATION ON UTILIZATION OF AGRICULTURAL WASTES AND NATURAL FIBERS.*

   Some centers may already be in existence or it may be possible to develop such activities at existing agricultural research, development and extension centers. Ideally, information dissemination, R&D, and extension should be coordinated activities.

3. *SUPPORT RESEARCH, DEVELOPMENT, AND DEMONSTRATION EFFORTS IN AND AMONG DEVELOPING COUNTRIES AS WELL AS PARALLEL COOPERATIVE EFFORTS BETWEEN DEVELOPED AND DEVELOPING COUNTRIES TO PRODUCE AND GAIN ACCEPTANCE FOR BUILDING MATERIALS AND TECHNIQUES AND OTHER NON-FOOD MATERIALS FROM AGRICULTURAL WASTES AND NATURAL FIBERS. KEY ELEMENTS OF SUCH EFFORTS INCLUDE:*

   a. Development of composite materials which utilize non-combustible carbonized plant materials and other agricultural by-products and wastes as light-weight, low-cost fillers, together with the development of non-petroleum-based binders from wood and agricultural products.

   b. Research and development directed at improved preservation treatments for organic materials and at plant breeding so as to improve their physical properties (e.g., fire resistance for thatch roofs.)

   c. Research and development directed towards new materials from un- and under-investigated food, fiber, and other crops not part of agriculture's mainstream.

   d. Research and development directed towards improved processes for the utilization of non-wood wastes and fibers in the production of paper.

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*Adapted from the ATRRU Study (19).

Table 4.1 (continued)

Research and Development Related Initiatives in Appropriate Technology for Building and Other Materials from Agricultural Waste and Natural Fibers

4. *SUPPORT EFFORTS TO GIVE MORE ATTENTION AND PRESTIGE TO R&D IN THIS AREA.*

   Use mechanisms such as greater involvement of international organizations, developing and developed country universities, and AT organizations working closely with village entrepreneurs and organizations in education, development, demonstration and extension efforts, as well as with developing country governmental bodies.

5. *SUPPORT EFFORTS TO DEVELOP AND ESTABLISH COLLECTION, TRANSPORT, AND STORAGE METHODS FOR AGRICULTURAL WASTES AND NATURAL FIBERS. KEY ELEMENTS OF SUCH EFFORTS INCLUDE:*

   a. Research and development directed towards determining when, what proportion of, and under what conditions some residues need to be left in fields to maintain field fertility. This should include research and development of biomass and excreta natural manures which which can be produced on-farm or through a local farm cooperative.

   b. Development of the collection or baling equipment or techniques and storage requirements necessary for each residue-product. (These elements will be a major key in the supply of homogenous, quality, raw materials to residue materials producers.)

   c. Expansion of solar drying technology research to include drying of residues as well as the primary crop.

development of these techniques will involve "a judicious choice of fabricating technique, a proper choice of components, and a careful study of how to protect small diameter fibers from deleterious reactions," with objectives that include:

> "1) maintenance of low cost through maximum utilization of indigenous resources and 2) improvement of impact strength, compressive strength, shear strength, and tensile strength so that the material can have potential for use as load-bearing structural elements." (52)

There have been a number of field projects, carried out in connection with organizations such as the Peace Corps, ITDG, and VITA, in which attempts have been made to add indigenous fibers such as grass thatch, bamboo, abaca and the like to soil, clay, cement, concrete, and other common building materials. The success of these attempts often hinges on the quality of the reinforcement, the stability and compatibility of the constituents and the method of fabrication. (10)

As noted in Section 3.2.10, agglomerated boards and panels can be produced from almost all agricultural residues and fibrous raw materials. What needs to be identified are the potential combinations of residue(s), binder, and processing method for each of the potential board or panel products. These potential products need to be identified also. While a product from a given combination of residue, binder, and processing method may not meet even the least demanding strength requirements, consideration should be given to alternative products, such as insulation material or packaging, or additional processing such as corrugating, laminating and/or sandwiching weak products with paperboard or similar material. Also, binders and processing methods need to receive more research attention. (Binders are discussed in Section 4.2.3). This R&D attention should be geared towards meeting developing country conditions of capital scarcity, small markets, and numerous underemployed rural laborers.

Processes which orient residue-binder composites offer great promise for producing structural products capable of substituting for lumber or steel. This is because orienting the residues in such composites gives them more strength than unoriented agglomerations. Research has shown that a low-cost pilot machine tested at the University of Massachusetts can produce a variety of products from residue-resin composites, from 2" x 4"s to H-beams, I-beams and curtain walls. (48)

Another important aspect requiring investigation is the possibility of adapting process equipment to more than one type of residue or fiber as a way of ameliorating supply fluctuations. This adaptation may involve residue pre-processing, simple modifications of equipment, change of binders, and/or change in product.

The most promising composite materials from agro-wastes and natural fibers are the various cement bonded panels, boards, and slabs that have been found to be simply and readily produced from most wastes. Some wastes have needed pre-treatment to remove cement-setting inhibitors like sugar, but otherwise these processes are not affected by economies of scale, do not require sophisticated equipment, and are quite readily adapted to labor-intensive production systems. (48, 58)

4.2.2 Carbonized Plant Materials for Aggregates and Fillers

Carbonization is a process which involves the controlled combustion of organic materials, usually in closed retorts* without the introduction of air, in which the organic material is separated into solid, liquid, and/or gaseous products. (133) The process also produces useful energy. Depending upon the process and organic material(s) used, products can have different uses, e.g. depending upon the specific gas produced, it may have value as a feedstock for the petrochemical industries, or as a fuel. The solid products, with the volatile gases and liquids driven off in the process, will not support flame, and they can burn only on their surface under an external flame source of about 425°C. (800°F). (19) Such burning deposits a fine ash on the surface which must be brushed away to maintain a fire. (133) The solid product has also been made biologically inert and highly resistant to water and most chemicals.

As was noted in the Principal Study (19), the steady diminution of world mineral resources combined with increasing transportation and handling costs of heavy materials suggests that increased attention needs to be placed on the use of renewable resources for construction and other materials. In some areas of the industrialized world, mineral aggregates have become scarce, leading to the design of roads with less gravel than is traditionally used (4), and spot shortages of traditional insulating materials -- as well as the need to improve their performance in order to improve upon energy conservation -- have

*Other processes, such as the one used by Professor Mehta to produce cement from rice hulls, can achieve effects similar to distillation in closed retorts.

motivated research into substitutes from natural, renewable resources. Developing countries which lack suitable mineral resources or the capital to exploit them, can find carbonized plant materials promising candidates for composite materials because of their production economics and renewability. (19) Because of their tropical or near tropical locations, many developing countries have huge biomass inventories, and are natural habitats for many fast growing species, some of which may be developed into carbonized fillers and aggregates. Carbonized materials' durability, safety, and light weight can make them attractive for use in urban building materials for developing countries.

Work undertaken at the University of Toronto on the carbonization of cereal grains which have been puffed has shown that the product of carbonization could be used as fill-type insulation at a lower cost than the polystyrene beads now used as a mineral substitute. (134) The product's insulation value results from its fine cellular structure which traps air. Such research, although useful, is limited because it deals with food materials urgently needed as such in developing countries. Carbonization research needs to be further diversified. As noted in the state-of-the-art review, Chapter 3, rice hulls, a waste, have been found to make useful aggregates, both burned and unburned, but information on research into carbonizing other wastes or non-edible plants or into the economic aspects of co-producing energy and material products is not readily available. Perhaps pyrolysis work such as that being done at Georgia Tech (48) could be diversified from its present energy/energy material production emphasis to include carbonized material co-production with energy/energy products.

If non-edible plants or wood can be identified as raw materials for carbonization, acreage which otherwise may be useful for growing food might be taken up for plantations of such crops. In order to avoid such a conflict, carbonization research should be directed towards agro-wastes, forestry wastes, natural fibers (which frequently suffer from limited marketing opportunities), and plants which can be or are grown on marginal lands not suitable for food crop production. (135) Additionally, research is needed into the development of low-cost processes which can be handled by local DC people, because research conducted to date indicates that less than intermediate-scale technology may be difficult to achieve. (19) Aside from the need for carbonization raw materials research, there is again the need for investigations to identify suitable binders, most especially those which can be developed from renewable materials.

4.2.3 Binders and Adhesives from Plant Materials

The problem of developing a good-quality waterproof adhesive from other than fossil fuel feedstocks and at a lower cost has been thought by some to be very difficult. (7, 38, 40, 48) The higher production costs and greater overall energy consumption required by other raw materials are thought to pose intractable problems in the search for binder substitutes from natural sources in developing countries; the only solution may be for DCs to adopt or adapt those techniques used elsewhere which reduce the amount of binders required. (48) Others are unconvinced that adhesives from agricultural products cannot be beneficially and/or economically produced in developing countries. (7, 38, 40) The major support for this second opinion arises from observations of proposals to establish a board or panel plant in a developing country in order to save on foreign exchange expenditures for imports; one finds that such savings are partly or completely negated by committing the country concerned to considerable expenditure on synthetic resin binders which they are unable to manufacture economically themselves.

From the state-of-the-art review, and the literature search behind it, this second view has the most support. A number of countries, both developed (Belgium and Finland are examples) and developing (India and Malaysia are examples), are conducting research into adhesives, binders, etc. from agricultural products according to the FAO's 1978 survey. (6, 78, 79) According to Chittenden (7), it is believed that the pioneering research work on such adhesives was done in Australia, where a particleboard binder based on wattle tannin and formaldehyde was developed over thirty years ago.*

During the AID-funded study to develop low-cost roofing composites for use in developing countries (115), which was discussed in the state-of-the-art review (Section 3.2.3), visits to a number of developing countries revealed the need to "drastically reduce the [foreign exchange] cost content of binding resins used for local plywoods, hardboards, and other composite panels used in industry (emphasis added). (19) The example from these visits (136) which

*This original work was expanded upon in South Africa, and this binder is now a technically acceptable binder where wattle tannin is economically available. (7)

was cited in the Principal Study shows the scale of costs associated with imported binders:

> "[A]t the National Housing Corporation prefabrication facilities in the Philippines, in 1974, urea formaldehyde binders accounted for 65 to 70% of the cost of particleboard produced for their houses; resin costs have further increased with raw material and transport costs in the last several years, and substitute binders are considered necessary by NHC if their housing obligations are to be met." (19)

Non-petroleum binders may be found in both organic and inorganic resources, and will be country or region-specific. Possible raw materials include various hydraulic-setting cements (perhaps from industrial wastes such as fly ash as well as from rice hull ash), limestone and gypsum, sulfur, asphalt and coal-tar derivatives, rubber and the latexes of other plants, animal proteins, clays, vegetable oils and starches.

Because many developing areas have large, underutilized stocks of wood and agricultural wastes (49, 147) containing lignin and furfural (two natural binders) in very high quantities, these appear to be particularly attractive candidates for binders from renewable resources. Lignin is found in all trees and the higher plants. It binds the cellulosic fibers together to form woody structure. Lignin content varies from roughly 20 to 40% of plant material. The furfural content of common agricultural wastes is also high, and in some wastes the combined content of the two is noteworthy: corncobs 30.4% lignin and 22% furfural; bagasse 20.3% and 17%; peanut shells 28% and 12%; rice hulls 40% and 12%. (128, 138)

Considerable data are available on lignin use in particleboard and other molded products, including a number of U.S. patents now in the public domain (124), and among these appear to be some relatively uncomplicated methods for extracting and treating lignin, such as might be suitable for consideration as low-capital investments by developing areas. Since the resin cost component of pressed and molded products is so high (30% and up (48)), dramatic improvements could be made in local availability and costs to users and in foreign exchange if resin source and processing methods were made local and simple. For tropical countries it would be necessary to provide integral protection against fungal and insect attack in most products; to this end research should include the potential for utilizing natural resources known locally for such characteristics, comparing them with additives already used elsewhere industrially for these purposes. Once viable candidates have been identified, preferably in parallel with preliminary research on fillers and aggregates, a comprehensive technical program can be directed at developing composites for specifically identified industrial needs.

Several agricultural residues and natural fibers such as wheat and rice straw, cotton stalks, corn (maize) stalks, bagasse, flax, hemp, and coconut fibers have been tested as fillers for slabs, boards, etc. bonded with cement. The equipment needed to manufacture cement-bonded boards from agricultural residues and natural fibers is similar to that needed for wood-wool boards, a viable technology in many areas. (38) Some modifications, however, are necessary as additional equipment for baling, storing, shredding, and depithing is required when agricultural raw materials are used. Certain fibrous materials contain cement-setting inhibitors which require mineralization before they can be used. Despite claims that the problems of cement-setting inhibition have already been solved, commercial applications do not appear to have been started, implying that further research and development work is necessary.

4.3 NEW AND IMPROVED MATERIALS

4.3.1 Material Improvement

In rural areas of developing countries, cost constraints and traditions of building dictate that materials should be used in familiar forms and by familiar methods. Although traditional builders have learned to select materials carefully for subtle variations in plant materials and, often, to work them in relatively sophisticated ways so as to optimize their performance, the working life of organic materials remains generally very short, and frequent repair or replacement continues to be necessary. Additionally, in some areas, bamboos, grasses, and leaf materials have become so scarce that although once free for the taking, they are now market commodities. Thus, improvement of the physical, mechanical, and building characteristics of traditional fiber materials -- the reeds, canes, grasses and bamboos -- would contribute significantly to improving the living conditions and economics of rural people throughout most of the developing world. Extending the life of traditional materials would be likely to have important long-term effects on rural communities' development and growth: There is little incentive to build amenities in housing which has a life-span of only 2 or 3 years. If the life of housing could be extended to, say, ten or twenty years, householders* would

*In this country the term used is usually homeowners. Because of tenure and land title conditions in many developing rural areas, houses are leased, occupy communal land, or have defacto use of land. Thus the term "householder" is appropriate.

be more likely to carefully and systematically consider solutions to their housing needs and perhaps adopt such health, time, and/or labor-saving facilities as integral water, sanitary, and cooking facilities. Additionally, authorities responsible for rural village planning would be able to set more rational land-use standards for housing and community development as functions of village and town growth needs. (53)

Traditional materials can be modified by chemical methods (preservative treatments), or by the selection and breeding of species to obtain superior physical and chemical characteristics for particular uses.

4.3.1.1 Material Improvement Through Preservation and Fire Retardance

Judging from the literature review, there appears to be little documentation of work in this area, but that is changing. As noted in Section 1.3.4.2, and in the Principal Study, (19) there is a sizable body of information available on the botanical, physical, and mechanical properties of plants (see, for example, reference (41)), but there seems to have been little scientific effort aimed at the identification and analysis of plants which have potential for meeting material needs or of improving other agro-materials. What literature or sources that are available have almost no overall organization, making information extraction difficult; traditional uses of some specific plants offer clues, however.

Additionally, there are a number of well-known methods to treat timber against termites, borers, and fungal attack, including pressure impregnation, the Boucherie method and ones adapted from it, and surface treatments accomplished by soaking, dipping, brushing, and/or spraying. However, these are, in general, not directly transferable to treating other commonly used plant materials, although pressure treatments have been adapted to bamboo and cane. (19, 139) Traditional rural developing country builders have devised their own local techniques, such as lime washes or tar coatings, although such techniques lose effectiveness over time through leaching and cracks and splits in the material from weathering.

Traditional uses of specific plants for improving the durability of natural materials include those as in West Africa, where techniques have been recorded for interlaying parts of the Cassia nigracamf plant in roof thatching, and for impregnating building mats with an extract from certain riverside trees, with both techniques providing some degree of termite protection. (53) In India (Punjab), agriculturalists mix dried waste fenugreek plants (Trigonnella foenum-graecum Linn., a spice plant) with cereal grains to protect them from the ravages of insects. (140) In India and in the West Indies, the Genip tree (Sapindaceae, sp., the Soapberry family) are known locally to have insect repellent properties. (53, 112)

A number of plant products have been employed for insecticidal protection throughout history; the major plants being of the Nicotiana species (for nicotine), the Chrysanthemum species (for pyrethrins), and the Leguminosae family (for rotenoids). Such natural insecticides degrade rapidly in light, heat, and air, but can have their effective life extended in certain solvents. (127) The leaves, bark, and fruits of the Persian Lilac or Bead Tree (Melia azedarach Linn.), which is grown throughout west and south Asia, are accredited with insect repellent properties. The leaves have been placed inside books and woolens; leaf extracts are used in sprays (unknown carrier solvent) to protect against locusts; and alcohol and petroleum ether extracts are reported effective in Ghana against Epestia ssp., and elsewhere against carpet beetles. (119)

In India, a cotton textile manufacturer has developed a durable flame retardant process for cloth using indigenous chemicals which are different from those in other known processes. (102) Research into the application of this or as yet undeveloped related or similar processes to grasses, bamboo, etc. may prove extremely valuable in preventing -- or minimizing -- fire damage to the thatch houses found in many DCs. (141)

In the current state-of-the-art of timber treatment, separate treatments are specified for insect and fungal damage on one hand and against fire on the other, although recent research has shown that a single treatment, using the organic resin amino phosphate, provides both fire and insect protection. It would be a large step forward if this or another single process which provides both types of treatment could be developed for developing country agro-waste/natural fiber applications, or as a minimum, a simple series of treatments that would enable the production of protected materials by a single manufacturer so that purchasers do not have to buy from separate sources, thus increasing their costs and logistical problems. For developing countries, such a goal would need to include the design of a process which can meet village skills, scales, needs, and capital. (53)

4.3.1.2 Material Improvement Through Plant Modification

There may well be opportunities for the breeding of plants to optimize specific material characteristics, just as cereal grains and other foodbearing plants have been improved. The process occurs in nature, such as with plants that develop survival methods against forest and prairie fires or in savannah areas where slash and burn farming is practiced. The concept is being applied in research on fire retardant plants for the California chaparral, where wildfires annually cause heavy property loss. (143) Since it is well known that certain trees and plants are more naturally resistant and durable than others, research should include a systematic search for plants with natural immunity to insect attack, resistance to fire through slow burning, inability to support flame, or charring characteristics that constitute self-insulation in fires. If exotic to developing areas, their ability to grow under local seasonal wet/dry cycles, their propagation, and ability to compete with native species would require study. If monoculture is implied for economic or logistic reasons, problems of disease susceptibility should be weighed against the benefits derived from plant selection.

Optimization of desirable characteristics would necessarily be a long-term undertaking, and it would be essential to carefully describe the performance required of the end materials for specific uses. Since it is unrealistic to expect to render cellulosic materials completely fireproof by any method, it would be important to understand the behavior and characteristics of fires under household conditions in the cultures concerned. Fire resistance in plants is a complicated subject, depending not only on the source, type, and character of the fire itself, but the moisture and chemical content of the plant, its mass and structures. A joint effort involving both building experts and botanists would be necessary to formulate the needs, acceptable performance standards, and codes that would apply in the utilization of such modified materials.

In Japan, techniques are known for the mechanical modification of the cross-section of bamboo, primarily for aesthetic reasons, by growing the culms through a framework that acts as a die so that, in effect, the plant extrudes itself into a square or rectangular shape. (144) Considering the great difficulty of fastening round bamboo at the joints of frames and trusses, it is surprising that work hasn't been directed at the modifications of shapes to improve and simplify building methods with bamboos and heavy canes.

4.3.2 New Materials

Although there are over a half million identified and classified species of plants growing on the earth, only a few thousand are cultivated to any extent; still fewer have been relatively well researched. (145) Research efforts undertaken in the U.S. and elsewhere during the agricultural depression of the 1920s and 1930s and during World War II showed that artificial fibers could be made from feathers, cotton, waste fibers, and waste milk. (145) Earlier research showed that peanuts and soybeans could be used to make quite a number of what were then new materials. (145, 146) In spite of these developments, research into new agro-materials has decreased steadily in the U.S. since World War II as the farm economy improved and petrochemical synthetics replaced many natural products. (147)

Within the many species of un- and under-researched plants there may be others like the soybean and peanut which can provide new materials for the future. Yet research like that mentioned above needs to be rejuvenated and increased. Present research techniques and equipment have reduced the time needed in the past for much agricultural research (148), and today there are considerably more agricultural research facilities throughout the world than there were when the above products were developed. Rejuvenating research into new materials may provide developing countries with a means of meeting their material needs, much as Mason's research at the USDA-ARS Northern Regional Research Laboratory produced masonite from timber wastes, thereby helping the American effort in World War II. (145) One of the major problems of agro-waste utilization -- satisfactory, inexpensive adhesives -- may benefit from this research. Adhesion, like rubber technology, is still as much an art as a science, and new binders may appear through research into the un- and under-investigated plant species.

4.4 NEW PAPER AND PAPER PULP TECHNOLOGIES

During the last half century, the paper industry's research and development efforts have been concentrated on the requirements of the basic processes and primary pulps -- from wood -- and improvements in plant and machinery, such as the change from batch to continuous operations, computerization/automation, and chemical recycling/recovery. Until recently, alternate technologies and raw materials which meet the specific needs of DCs have received little R&D. From the literature review, it is clear that much work is needed to improve the quality and strength of paper produced in small-scale plants, to recover the chemicals used, and to devise suitable pulping processes for non-wood fibers.

Because most developing countries lie in the tropics, with primarily hardwood forest resources, they are usually deficient in species of trees such as pine, fir, etc. for the production of long-fiber pulp. While many wastes and fibers from agriculture could provide both short- and long-fiber pulp, both the collection systems and processing technology need further development. Specific pulping processes for the various pulp sources need refinement, and recovery methods developed so that the cooking chemicals and some of the pulp are not lost. Some small-scale plants now in operation use the "old-fashioned" chemical recovery system which has low heat economy.

Although paper and paper products have been made from short-fiber wheat and rice straw (149), further R&D is needed to overcome technical problems associated with their use in order to facilitate their more wide-spread use in wheat and rice growing areas. (74) Additionally, research is needed into means by which the need for long fiber pulp can be eliminated or minimized as many agricultural residues can provide only short fibers. (114, 150)

Because the residues and fibers used in such processes will vary from season to season in a given area, and the markets to be served will probably be of limited sizes but with diverse product requirements in each market, the development of more versatile paper machinery is necessary. Such improvements as the combi-press pick-up, grooved and fabric presses, and substance and moisture control which have been achieved in the high-capital technologies may be incorporated into such machinery, perhaps in a modular component type of construction so that initial costs can still be kept low, but expansion allowed for.

There is considerable technological expertise of the required sophistication for small-scale, agro-waste and natural fiber paper production in a number of developing countries like Brazil, India, and Egypt. Assisting cooperation and interaction between these DCs and other DCs can benefit both DC groups as well as the U.S., and can be accomplished through bilateral, multi-lateral, and international mechanisms. Specific actions which might be taken by the U.S. follow:

> "(a) Establish a comprehensive data bank on the small-scale technologies developed and ... in operation in some of the developing countries using non-conventional fibres;
>
> (b) Participate, both financially and technically, in national R&D projects in the field of small-scale pulp and paper technologies;
>
> (c) Assist in establishment of regional research centres for R&D on specific alternative raw materials, which are or may be available in these regions;
>
> (d) Facilitate transfer and application of small-scale technologies from developing countries where such technologies are in operation to other developing countries by providing requisite advisory services to that effect, to the latter; and
>
> (e) Assist developing countries in formulating comprehensive production programmes which would include establishment of production capacities for critical varieties of paper and paper products." (74)

Specific actions of bilateral nature endorsed by the UNIDO Forum on Appropriate Industrial Technology include:

> "(a) Assessment of the long-term domestic requirements of paper on the basis of present consumption and growth trends taking into account increase of population, progress of education and overall development.

(b) Identification of appropriate small-scale technologies based on non-wood fibres now in operation in some of the developing countries and assessment of their suitability to local conditions;

(c) Establishment of indigenous capability for the fabrication of plant, equipment and components based on existing small-scale technologies and processes;

(d) Formulation and implementation of crash programmes for the development of plantations for production of coniferous and other long-fibre species both as part of afforestation programmes and independently of it; and

(e) Encouragement, through a rational scheme of financial and technical assistance as well [as] fiscal subsidies, of the establishment of small-scale paper mills as adjunct to the existing and future sugar and timber mills." (74)

4.5 COLLECTING, PROCESSING, AND SUPPLY RESEARCH NEEDS

4.5.1 Collection and Transport

The first phase in the use of agricultural residues and those natural fibers not currently part of a market structure involves two situations of collection and transport. These situations are: a) when such wastes are produced by mills or are concentrated in a small area; and b) when the wastes are distributed over a large area. In the first case, collection and transport do not present special difficulties unless the quantities are economically insufficient, because processing facilities can be established near these points.

When wastes are not concentrated, the costs of collection and transportation to the processing site may be higher than the cost of other, non-waste materials. Additionally, some countries have forbidden the removal of certain residues from their fields in order to protect the fertility of the soil, prevent erosion, and/or prevent the spread of insect pests. In other countries, such as Egypt and Iran, legislation makes it compulsory to burn cotton stalks in the field. (48) In Fiji, and elsewhere, sugarcane tops are burned in the field to reduce insect and disease damage and to clear the ground for the next planting or rattan growth. (151) Such situations as these add to collection difficulties, and further endorse what an FAO conference long-ago noted: "[T]he greatest obstacle to increasing the utilization of many of these non-wood materials is the problem of collection and storage and the lack of suitable equipment, for th[ese] purpose[s]." (152)

That this argues for continuing the development of small-scale processes for utilizing such wastes should be obvious. In the early days of industrialization, many marketable non-food agricultural crops were collected manually and transported relatively small distances to processing centers that were extremely small by today's standards. With a collection system -- primarily a soft technology -- established, a focus was provided for research to identify and develop useful equipment like mowers and balers that made collection easier and used transportation more efficiently by reducing the materials' bulk. Small-scale processes which convert dispersed wastes such as cassava stems (those not used for planting) and coconut husks* into particleboard could create the system necessary to make intermediate- and larger-scale processes viable.

Research such as that conducted over a decade ago by the Tropical Products Institute (TPI) and others (7) into the problems of

*In many countries husks are not centrally collected in very large quantities but are left in the coconut groves.

collecting and transporting materials not located at central, primary processing, sites needs continuation. Process scales smaller than those looked at in the past may be a key to solving the dilemma. For those residues such as cotton stalks and banana stems which, although dispersed, are predominantly in fields with no other plants, the problem is a bit less severe, because collection can be more readily undertaken by equipment as was the case with maize, straws, etc.

Investigation is also needed into strictures against the removal of agricultural wastes from the field and those which require in-field burning of the wastes. In some agricultural systems, it is cheaper* to remove plant residues from the field because of labor cost savings both in clearing-off the waste rather than cutting and burning it and in reduced preparations at the next planting. (63) Although it has been shown (63) that the removal of wastes for further processing, with field fertility maintained with commercial fertilizers, is economically viable, much work appears to be needed: the use of commercial fertilizers reduces the cash return to the farmer. Answers to the problem may involve the development of techniques for on-farm (or farm co-op) production of natural manures from biomass and excreta, the determination of permissible waste removal limits for given crops and soils, the development of crop rotation techniques which permit removal with soil fertility maintained by fallow crops, and the development of small-scale technologies for the production of chemical fertilizers from biomass.

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*About $20 per acre less is cited by Huang in his paper. (63)

4.5.2 Storage and Fire Protection Requirements

The use of agricultural residues and those natural fibers which are not currently part of a market structure involves a second phase of storage and fire protection. Many residues and fibers are generated in relatively large amounts for only short portions of the year and may be needed to supply a plant's raw materials needs over the balance of the year. Labor may also not be available for processing during the period of waste production and collection as well as those times of the year when agricultural cultivation and planting occur. Until processing can be undertaken, they will need to be kept someplace and protected from deterioration; fire protection may also be necessary as some residues are more flammable than sawdust (48), in part because of their higher sugar content. Expert's opinions on the solvability of the problems of storage and fire protection vary from "the problem of ... storing good potential particle board ... appears unsolvable.." (38) to "... there are no serious problems of storage, fire protection or special regulations that would affect the utilization of organic wastes in developing countries." (48)

A more realistic assessment of the matter appears to have been best stated by A. E. Chittenden of the Tropical Products Institute (TPI). Chittenden says that storage is just "another problem facing the potential user of agricultural wastes [because they] are produced for only a short period of the year [,] are bulky," and may "have to be dried." (7) What is clear from the literature is that the technical requirements for storing organic materials for each given process need definition. Beyond these technical parameters, "storage is a purely economic problem ... because of the bulky nature of these materials." (7)

While many agricultural wastes are produced in a dry or nearly dry state, many of the processes in which they can be used require that they still be dry when they are used.* This means that storage may have to be under cover. But perhaps research will develop for other materials techniques such as those used in India to protect baled bagasse from rain wetting without a roof. There, the top and outer bales of the stack are sprinkled with boric acid to prevent rotting due to rain wetting. (112) Bagasse is produced in a wet state (about 50 percent water content) (7), and is dried naturally during such storage through airways let through the stack. Another method of protection used in India is the addition of 1 percent of propionic acid to the bagasse; this has been found to render ineffective the microorganisms which cause the deterioration of the stored bagasse as well as the disease bagassosis (see Section 3.2.2). (7, 112) Bagasse also contains small amounts (2 to 6 percent) (112) of residual sugar, and such aerated stacks reduce the likelihood of exothermic ignition caused by heat build-up from the sugar's fermentation. (48)

4.5.3 Supply of Raw Materials

Government support for the establishment of agro-waste/natural fiber industries for the production of building and other materials

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*Processes for solar drying of the primary product(s) from a given crop were reviewed in the Principal Study. (19)

will, like the establishment of other agro-industries, be a stimulus to farmers to grow, collect, and transport the specific raw materials demanded by these industries. (18) Experience in other agro-industries has shown, however, that this stimulus is not always sufficient to guarantee the production of the quantities and specific types of raw materials exactly as they will be needed by the industries concerned. Supplies of raw materials to these industries have to be of consistent quality and regularly supplied in certain minimum amounts to enable the industries to plan their storage and production policies.

While small-scale agro-waste industries should be less affected by these supply difficulties, their growth may not be possible unless systems are developed to ensure the delivery of an adequate supply of raw materials to them. As a rule, cautious methods of developing agriculture usually prove insufficient to meet these difficulties. (18) For this reason, in many parts of the world, agro-industries satisfy their basic requirements by establishing their own supplies. (18) Research is needed into the application of the two basic ways of establishing such raw materials supplies to smaller-scale rural industries (industries which may be cooperatively owned). One of the basic ways is to establish a farm under the relatively direct control of the factory; the other is for the factory to make contractual arrangements with a number of farms. In actual practice, most agro-industries use both methods simultaneously. (56) The right combination of the two ways depends on the availability of an appropriate farming community, on the management of the industry, on the general state of agricultural development in the area, and on many other factors.

Consideration also needs to be given to the overall problem of agro-waste/natural fiber supply. While the quantities in Table 2.1 give an idea of the availability of the most common agricultural residues and fibers, these do not appear to have been correlated with the quantity demands of their potential uses. Stated another way: How much of the materials needs of developing countries can be significantly or entirely met from agricultural residues and fibers? To answer this question, it will be necessary to look at each individual residue/fiber process and product so that substitutabilities can be accounted for; it will also be necessary to allow for current uses, such as the production of furfural from corn cobs and oat hulls and traditional uses like thatching and fuel. Answers to these questions will be needed by potential investors in the processes for using agricultural wastes and natural fibers, and they will be useful for determining priorities for research.

4.6 SUMMARY OF RESEARCH AND DEVELOPMENT NEEDS AND INITIATIVES

The most prominent theme in this discussion of research and development needs and initiatives for appropriate technology for agro-waste and natural fiber materials is that agricultural research ought to be increased in both quantity and diversity. As was noted earlier, it is not enough for agricultural research efforts to develop methods for increasing agricultural productivity. Rural developing country residents need to have access to income- and employment-generating activities besides crop production if rural development programs are to be successful. Agricultural research directed towards building materials industry uses of the residues from food and fiber production and processing would be a step towards meeting this need.

A measure preliminary to this research and development is the assessment of agricultural residues availability and the present alternative uses to which these materials might be put. This measure will involve the technical factors of residue supply and product possibilities as well as planning, policy study, and evaluation of economic, political, cultural, and environmental factors. In close conjunction with this preliminary measure, efforts will be needed to give increased attention and prestige to research and development in the area of agro-waste/natural fiber materials, and support will be needed for the establishment of centers and networks to collect, evaluate and disseminate information on new and already developed methods for utilizing agro-wastes and natural fibers in building and other materials. Increased attention and prestige will probably result from encouraging the greater involvement of various institutions in this field. Centers and networks may be established by using existing agricultural research, development, and extension centers as a nucleus.

Specific research and development efforts with promise include the development of composite materials from both carbonized and uncarbonized agricultural residues and natural fibers, the development of agricultural-/silvicultural-residues and natural fibers, the development of improved fire and rot resistance treatments, and plant breeding R&D to maximize desirable characteristics. Other R&D efforts needed include improved processes for the utilization of these raw materials in paper production, the investigation of un- or under-researched plants, and systems for the collection, transport, and storage of the agricultural residues and natural fibers which are to be used in materials production. The major foci of R&D efforts into the problems of collecting, transporting, and storing these renewable resources will probably involve determining when residues can be best removed, developing collecting or baling techniques or equipment, and determining appropriate storage processes or facilities.

These measures are proposed as basic steps in the increased production of building and other materials from natural fibers and agricultural residues. Information gained from them should provide the necessary direction for further research and development efforts.

5. ORGANIZATIONS AND MECHANISMS FOR INITIATIVE IMPLEMENTATION

5.1 INTRODUCTION

The means for implementing initiatives in appropriate technologies for processing agricultural residues and natural fibers into building and other materials are the organizations involved in the process and the mechanisms which are used to unite the efforts of such organizations in the aggrandizement of these technologies. In this chapter, those institutions which have been involved in, or which have the capabilities to become involved in, research and development* of appropriate technologies for the production of building and other materials from agricultural residues and natural fibers are reviewed, together with the mechanisms through which they may be employed. The organizational review examines three different groupings: domestic U.S. organizations; developing country organizations; and international and other developed country organizations. The mechanisms suggested for the development and transfer of appropriate technologies for building and other materials from agro-wastes and natural fibers are rather broad and diverse. This is done to allow for the maximum flexibility of options available to both the domestic and developing country organizations. Many of the discussions of the mechanisms were developed during the Principal Study. (19)

*"Development" in this sense includes financial, technical, and administrative extension; some writers refer to this process as "research, development, demonstration, and commercialization".

5.2 ORGANIZATIONS: THEIR INVOLVEMENT AND CAPABILITIES

Listed in Tables 5.1, 5.2, and 5.3 are organizations which have been identified as being recently involved in research and development work on building and other materials from agricultural wastes and natural fibers. The list was compiled from a number of sources, including a survey by the UN's Food and Agricultural Organization (FAO) (6, 78) and an Expert Working Group meeting sponsored by the UN's Economic and Social Affairs Department. (48) While the organizations listed in the tables cannot be considered a complete listing, based upon the information available they represent organizations which appear to be very active and prominent in this field. Many of the organizations listed have possibly had little or no exposure to capital-saving technologies; however, it is assumed that they could in fact make contributions to the field, especially in light of the large volume of crops (60) and their potentially derivable products (3) which have had little investigation.

In addition to the organizations listed in the tables, there are many other organizations which have been involved in the past, or have the capability for future involvement, in research and development on building and other materials from agricultural wastes and natural fibers. For example, the Asian Institute of Technology, Bangkok, Thailand, which has been involved in a number of research projects into food, feed, and fuel products from agro-wastes (6, 78), developed the water filter media mentioned in Chapter 3; the Technology Consultancy Centre of the University of Science and Technology, Kumasi, Ghana; and the Institute for Small Industries at the University

Table 5.1

List of U.S. Organizations Dealing with Research on Manufacturing Building and Other Materials from Agricultural Residues and Natural Fibers

Name and Address	Raw Material(s)	Product(s)
USDA-ARS Eastern Regional Research Center 600 East Mermaid Lane Philadelphia, PA 19118 (A,B,C)*	Hides	Acoustic tile
USDA-ARS Richard B. Russell Agricultural Research Center P. O. Box 5677 Athens, GA 30604 (B,C)	Fruit and vegetable wastes	Plywood adhesives
USDA-ARS Northern Regional Research Center 1815 N. University Street Peoria, IL 61604 (Attn: C. W. Hesseltine) (A,B)	Straw Corncobs Manure	Paper Industrial products Hardboard
USDA-ARS Naval Stores Laboratory P. O. Box 1 Olustee, FL 33880 (B)	Resins, resin acids, etc.	Naval stores

*See notes at end of Table 5.3 for sources of information cited.

Table 5.1 (continued)

List of U.S. Organizations Dealing with Research on Manufacturing Building and Other Materials from Agricultural Residues and Natural Fibers

Name and Address	Raw Material(s)	Product(s)
Mr. Poo Chow Dept. of Forestry College of Agriculture University of Illinois Urbana, IL 61820 (A,B)	Cornstalks, cobs, husks; peanut hulls; sunflower seed hulls; kenaf stalks; cotton stalks	Particle board, fiberboard, hardboard
Mr. M. R. Overcash N.C. State University Dept. of Biological and Agricultural Engineering P. O. Box 5906 Raleigh, NC 27607 (A,B)	Manure	Insulation board
Dept. of Agronomic Crop Science Oregon State University Corvallis, OR 97331 (B,C)	Grass and cereal crop residues	Particleboard
Department of Forest Products Forestry Research Laboratory Oregon State University Corvallis, OR 97331 (B)	Rye grass straw	Corrugating paper

Table 5.1 (continued)

List of U.S. Organizations Dealing With Research on Manufacturing Building and Other Materials from Agricultural Residues and Natural Fibers

Name and Address	Raw Material(s)	Product(s)
American Agricultural Industries, Inc. 9505 West Devon Avenue Rosemont, IL 60018 (Attn: Thomas J. Army, Ph.D., Vice President) (B)	Agricultural wastes generally	Fibers
Mr. Eldon C. Beagle The Beagle Corporation P.O. Box 874 West Sacramento, CA 95691 (A,B)	Rice husks ash/char	Insulation, filter media
URS Corporation 1811 Trousdale Drive Burlingame, CA 94010 (B)	Rice husk ash	Water filter
URS Research Company Environmental Systems Division 155 Bovet Road San Mateo, CA 94402 (B)	Rice husks	Cement, board, sodium silicate
The National Center for Appropriate Technology (NCAT) P.O. Box 3838 Butte, MT 59701 (G)	Cellulose, general	Insulation

Table 5.2

List of Developing Country Organizations Dealing With Research on Manufacturing Building and Other Materials from Agricultural Wastes and Natural Fibers (by Country)

Name and Address	Raw Material(s)	Product(s)
BANGLADESH		
Bangladesh Sugar Mills Corp. Shilpa Bhaban Motijheel Commercial Area Dacca, 2 (B)*	Bagasse	Paper
COLOMBIA		
Universidad del Valle Chemical Engineering Dept. Apartado Aero 2188 Cali (B)	Rice husk Bagasse	Activated charcoal
CUBA		
ICIDA Via Blanca y Carretera Central Apartado 4026 La Habana (B,C)	Bagasse	Board, industrial textiles paper pulp, furfural, carbon

*See notes at end of Table 5.3 for sources of information cited.

Table 5.2 (continued)

List of Developing Country Organizations Dealing with Research on Manufacturing Building and Other Materials from Agricultural Wastes and Natural Fibers (by Country)

Name and Address	Raw Material(s)	Product(s)
FIJI		
Ministry of Forests Principal Utilization Officer Government Buildings Suva (B,D)	Coconut Wastes	Fiber mats, activated charcoal, building materials generally
GHANA		
University of Science & Technology Kumasi (C)	Cassava, plantain wastes Banana wastes	Glue Waterproofing
Building and Road Research Unit Kumasi (C)	Rice husk ash	Bricks
HAITI		
Institut de Dévelopment Agricole et Industrial P.O. Box 1313 Port-au-Prince (B)	Whey, buttermilk, cotton linters and seed cake	Baseballs, mattress stuffing
INDIA		
Council of Scientific and Industrial Research (CSIR) Rafi Marq New Delhi 110001 (A,B)	General	General

Table 5.2 (continued)

List of Developing Country Organizations Dealing with Research on Manufacturing Building and Other Materials from Agricultural Wastes and Natural Fibers (by Country)

Name and Address	Raw Material(s)	Product(s)
INDIA (continued)		
CSIR Regional Research Lab. Jorhat 785006 (A,B)	Rice husk	Bricks, cementitious material, board
	Corn cobs	Fufural
CSIR Regional Research Lab. Canal Road Jammu Tawi (A,B,C)	Rice straw, pine needles, menthe grass, bagasse, general	Fiberboard, particle board, furfural
National Chemical Lab Poona 411008	Coconut pith	Gaskets
	Sugar-cane press mud	Waxes
Indian Plywood Industries Research Institute Bangalore 560022 (A,B)	Various wastes	Extender for synthetic resins, resin
	Cane wastes	Treated roofing mats
Central Building Research Institute (CBRI) Roorkee, U.P. (A)	Rice husks	Mortar
	Jute sticks	Particle board
	Coconut pith	Particle board, expansion joint filler
	Coconut coir	Roofing sheets, boards, insulation concrete

Table 5.2 (continued)

List of Developing Country Organizations Dealing with Research on Manufacturing Building and Other Materials from Agricultural Wastes and Natural Fibers (by Country)

Name and Address	Raw Material(s)	Product(s)
INDIA (continued)		
Jadavpur University Dept. of Food Tech. and Biochemical Engineering Calcutta 700032 (B)	Rice husk	Silica, compressed board
INDONESIA		
Asian and Pacific Coconut Community P. O. Box 343 Jakarta (A,B)	Coir dust	Particleboard, insulation board, charcoal, activated carbon
Institute of Technology Bandung Dept. of Chemical Technology Jalan Ganesya 10 Bandung (A,B)	Rice hulls Bagasse	Furfural, waterglass Paper pulp
IRAN		
Engineering Laboratory Institute of Standards and Industrial Research (E)	Rice hulls	Blocks

Table 5.2 (continued)

List of Developing Country Organizations Dealing with Research on Manufacturing Building and Other Materials from Agricultural Wastes and Natural Fibers (by Country)

Name and Address	Raw Material(s)	Product(s)
MALAYSIA		
Department of Forestry Forest Research Institute Kepong, Selangor (A,B)	Empty fruit bunches from oil palm	Paper pulp
MAURITIUS		
Sugar Industry Research Institute Reduit (B,C)	Bagasse	Particleboard
MOROCCO		
Ministry of Agriculture and Agrarian Reform Rabat (B,C)	Rice bran Maize germ	Glue Paint
	Fruit and vegetable wastes	Board, glue
NEPAL		
Tribhuvan University Kathmandu (F)	Sugar mill wastes	Cement

Table 5.2 (continued)

List of Developing Country Organizations Dealing with Research on Manufacturing Building and Other Materials from Agricultural Wastes and Natural Fibers (by Country)

Name and Address	Raw Material(s)	Product(s)
PAKISTAN		
Pakistan CSIR Labs Off: University Road Karachi 39 (B,C)	Rice husk, jute cuttings, rice straw, wheat straw, bagasse, rubber wastes	Various boards, paper
Forest Products Research Div. Pakistan Forest Institute Peshawar (B)	Rice and wheat straw, bagasse	Chipboard, paper
PHILIPPINES		
Philippine Council for Agriculture and Resource Research (PCARR) Los Baños Laguna (A,B)	Cassava stems	Particleboard
NACIDA[2] (P.C.A.) Los Banos, Laguna (B)	Coconut husks	Insulation board
FORPRIDECOM College, Laguna 3720 (A,B,C)	Rice straw, bagasse, banana fibers, abaca fibers/stalks, coconut husks	Fiber and particle board, tannins, adhesives, blocks, tile, activated charcoal, paper pulp

Table 5.2 (continued)

List of Developing Country Organizations Dealing With Research on Manufacturing Building and Other Materials from Agricultural Wastes and Natural Fibers (by Country)

Name and Address	Raw Material(s)	Product(s)
PHILIPPINES (continued)		
National Grains Authority 1424 Queson Blvd. Extn. Quezon City (A)	Rice husks	Carbonized blocks
THAILAND		
Ministry of Industry Scientific Department Rama VI Road Bangkok (B)	Rice straw	Paper pulp
TRINIDAD AND TOBAGO		
Caribbean Industrial Research Institute University P.O. St. Augustine (B)	General	Building materials
URUGUAY		
Chemical Facul y Cátedras de Proyectode Fabrica y de Química Industrial y Control Analítica General Flores 2124 Montevideo (B,C)	Rice husk, bagasse, linseed and sunflower seed husks	Building material

Table 5.3

List of Non-U.S. Developed Country Organizations Dealing with Research on Manufacturing Building and Other Materials from Agricultural Wastes and Natural Fibers (by Country)

Name and Address	Raw Material(s)	Product(s)
AUSTRALIA		
CSIRO Division of Protein Chemistry Leather Research Group 343 Royal Parade Parkville, VIC. 3052 (A,B,C)*	Tanned leather	Acoustic tile
CSIRO Division of Forest Research P.O. Box 4008 Canberra, ACT 2600 (B)	Branches, tops & leaves, chips	Boards, pulps for paper
CSIRO Agro-Industrial Research Unit P.O. Box 1666 Canberra, ACT 2601 (A)	Straw	Pulp
Southern Sugar Experiment Station Division of Mill Technology P.O. Box 651 Bundaberg, QNSLND 4670 (b)	Bagasse	Packaging

*See notes at end of table for sources of information cited.

Table 5.3 (continued)

List of Non-U.S. Developed Country Organizations Dealing with Research on Manufacturing Building and Other Materials from Agricultural Wastes and Natural Fibers (by Country)

Name and Address	Raw Material(s)	Product(s)
AUSTRALIA (continued)		
Sugar Research Institute P.O. Box 21 MacKay, Queensland 4740 (B)	Bagasse	Paper
CANADA		
Cor-Tech Research Ltd. 426 Vanguard Rd. Richmond, B.C. V6X 2P5 (A,B,C)	Rice Husk Cereal straw	Boards: composite boards, hardboards, fiberboards
DENMARK		
Bioteknisk Institute Tilknyttet Akademiet for de Tekniska Videnskaber Holbergsvej 10 6000 Kolding (A,B,C)	Cereal straw	Particleboard, paper board
FINLAND		
Rintekno Oy Consulting Engineers Kotkapolku 2 02620 Espoo 62 (B)	Bagasse, rice husks, corn cobs, almond shells	Furfural, active carbon

Table 5.3 (continued)

List of Non-U.S. Developed Country Organizations Dealing with Research on Manufacturing Building and Other Materials from Agricultural Wastes and Natural Fibers (by Country

Name and Address	Raw Material(s)	Product(s)
FINLAND (continued)		
The Finnish Pulp and Paper Research Institute P.O. Box 136 00101 Helsinki 10	Straw	Pulp
JAPAN		
University of Tokyo Faculty of Agriculture Dept. of Forest Products 1-1-1 Yayoi, Bunkyo-ku Tokyo (B)	Bagasse	Fiberboard, particleboard
International Projects, Ltd. 3rd Floor, Komiyama Bldg. 2-32 Roppongi 3-Chome Minato-ku, Tokyo (B,C)	Jute stalks	Particleboard
SOUTH AFRICA		
Huletts Sugar Limited P.O. Mount Edgecombe 4300 Natal (B)	Bagasse, sugarcane filter mud	Board, paper, furfural, wax

Table 5.3 (continued)

List of Non-U.S. Developed Country Organizations Dealing with Research on Manufacturing Building and Other Materials from Agricultural Wastes and Natural Fibers (by Country)

Name and Address	Raw Material(s)	Product(s)
SOUTH AFRICA (continued)		
Hulsakane Ltd. Private Bag 3 Glenashley 4022 (A)	Bagasse	Particleboard
UNITED KINGDOM		
Tropical Products Institute 127 Clerkenwell Road London ECIR 5DB England (A,B)	Bagasse, groundnut husks, rice husks, arrowroot "bitty"	Particleboard, lightweight blocks, packaging

Sources for Tables 5.1, 5.2, 5.3:

A - Agricultural Residues: Compendium of Technologies, FAO, Rome, 1978.

B - Agricultural Residues: World Directory of Institutions, Revision 1, FAO, Rome, 1978.

C - Use of Agricultural and Industrial Wastes in Low-Cost Construction, UN (ESA), New York, 1976.

D - "The All Coconut House" FIJI, Vol. 1, No. 4, September-October, 1978, page 2.

E - "Agricultural Waste as a Civil Engineering Material," Small Industry Journal, Vol. 7, No. 3, March 1975, pp. 3-33.

F - Appropriate Technology in India, J.W. Powell, University of Science & Technology, Kumasi, Ghana, 1978.

G - Response from NCAT to Principal Study survey.

of the Philippines. (96) These are a few of the developing country institutions in this category. A number of developing country governmental R&D organizations, while not noted for specific processes or technologies in the FAO publications (6, 78), are interested in doing research on agro-waste and natural fibers materials.

In the United States, many private agricultural industry organizations, like the Armour Food Company and General Foods Corporation (78) have long been engaged in R&D on food and feed products from agricultural by-products, and they may be useful in materials R&D. Federal laboratories have gained some experience with agro-waste materials, although their research focus has generally been elsewhere. University involvements, such as the Center for Development Technology's (CDT) collaboration with the Universidad Industrial De Santander, Colombia, the Universidad National Autonoma de Mexico, and with Monterrey Tech (Mexico) on the development of composite roofing materials for tropical areas (153), and Lehigh University's conference on New Horizons in Construction Materials (154) appear to be more numerous than reported.

Other organizational resources include independent research institutions like Southwest Research Institute and "appropriate technology" (AT) organizations. One of the oldest and preeminent of the AT organizations in the U.S. is Volunteers In Technical Assistance (VITA), which was founded twenty years ago to answer requests for technical assistance.

5.2.1 U.S. Organizations

The organizations listed in Table 5.1 can be classified as: universities, federal laboratories, appropriate technology organizations like VITA, and private industry. In addition to these are private volunary organizations (PVOs) like CARE, the Peace Corps, and funding organizations.

Universities are logical focal points for cooperative international R&D efforts in building and other materials from agro-wastes and natural fibers. While universities are a significant portion of the organizations listed in Table 5.1, many more universities are involved in research on non-material (i.e., food, feed, and fuel) products from agricultural wastes (6, 78) and could develop capacities in materials research. In a previous CDT study (27) it was noted that many U.S. universities have had extensive international involvements, have the resources to bring to such efforts, and, importantly, have large populations of students from developing countries who could directly benefit from the experiences gained in such efforts. The major inhibitor to university involvement, as with many U.S. organizations, is their need for external financing of such research.

Federal laboratories, specifically those of the Department of Agriculture's (USDA) Agricultural Research Service (ARS), have been active in some of the potential wastes/materials areas. The USDA's ARS was established in the late 1930s to find or develop alternate products from agricultural crops, and to explore new potential crops and their product possibilities (145), but has since had its mission expanded to include research into almost all the problems of agriculture. (147) The USDA, in addition to having research and development capabilities in this thesis' subject area, also has experience in grass-roots extension and in educating foreign agriculturalists through the International Programs of the USDA Graduate School.

As with universities, the federal labs have had more involvement in non-materials agricultural R&D, with considerable emphasis currently placed on pollution control or abatement rather than resource development. (6, 78) Although there is some activity and capability at federal labs, there is no mission to become heavily involved in agro-materials development, and little to become at all involved internationally. Additionally, there are those federal -- and other -- labs that have developed composite materials expertise in conjunction with U.S. space and defense research which could possibly be utilized.

Appropriate Technology (AT) organizations are probably the best group of institutions for knowing the kinds of problems and needs of people at rural grass-roots or village level, but it must be kept in mind that many AT organizations in the U.S. have limited international experience. What may be appropriate, capital-saving, technology in the U.S. may be inappropriate, for reasons of culture, economics, or politics, in developing countries. The primary U.S. appropriate technology organization with international experience to date has been VITA*, which has stressed problem solving and information dissemination.

Over the years, VITA has handled over thirty thousand requests for technical assistance, most from developing countries. In addition, they have produced handbooks on low-cost construction, health, and agricultural techniques based upon their experiences. As part of these activities, VITA has held panels on various topics, including a 1976 panel on wood waste utilization cited in Chapter 3(84), and maintains an extensive library of appropriate technology-related

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*VITA headquarters are at 3706 Rhode Island Ave., Mt. Rainier, MD 20822.

publications. (84) In a visit to VITA's offices earlier this year, it was found that requests for "agricultural wastes" and "waste utilization" accounted for only a small number of the information requests received by VITA, but that the number of requests in the housing, construction, and rural industrialization areas was substantial.

The New Alchemy Institute, which is heavily involved in S&T applications and development has had a good amount of international exposure. A.T. International (A.T.I.), created in response to Congressional mandate in 1977, stresses problem solving with local resources according to local needs and priorities. (155) A.T.I.'s activities to date have focused on assistance to commercial organizations and support of AT resource centers in developing countries. Unlike most other AT organizations, A.T.I. is primarily a funding agency with a mandate to "promote the development ... of technologies appropriate for developing countries" (155), and could conceivably support project-specific research in the area of this thesis, although A.T.I.'s lack of research orientation may inhibit such activities. (155, 156) As noted in the Principal Study (19), a summary of some of the potential contributions of U.S. AT organizations is presented in a report edited by Smith (157), and in an earlier directory prepared for the National Science Foundation/Research Applied to National Needs (NSF/RANN). (69)

While private industry's role in the development of capital-saving technologies for producing building and other materials from agricultural wastes and natural fibers has received little emphasis in this or the Principal Study, there is considerable research effort being conducted by private industry into agro-waste products. Much of this effort by food and feed companies, as with government and university efforts, goes toward the production of food, feed, and fuel products from what had been a source of pollution. (78) The principal reasons for the little attention given to private industry in this study is lack of information due to the general reticence of private industry regarding current or potential proprietary processes. The private industrial organizations listed in Table 5.2 are examples of the small and medium firms (as opposed to large firms like General Foods and Armour) often mentioned as possible contributors in international technology activities. (19) Private industry has used its capabilities in conjunction with universities in the development and transfer of technology for processing agro-wastes and natural fibers, as shown by the Monsanto-Washington University-University of Washington project mentioned earlier. (103, 115)

Additional organizations not listed in Table 5.1 also have capabilities and/or experience related to this field. Private Voluntary Organizations (PVOs) like CARE and the Foundation for Cooperative Housing (FCH) (11) support field projects related to or in this area. In some cases they can provide funding as well as technical resources. Research institutes like the Southwest Research Institute (SWRI) have already been involved; SWRI has held several conferences on construction and materials for developing countries. Other institutes like Batelle Memorial Institute and the Denver Research Institute (DRI) have capabilities for participating. Batelle has been involved in materials research for space and defense applications; DRI has been involved in village-level food processing programs with AID support. The Solar Energy Research Institute (SERI) has been reviewing international development activities in renewable resources (158), and might be useful for R&D in the areas of carbonization (or pyrolysis) for energy materials and carbonization for building materials development. (See Section 4.2.1.2)

Peace Corps Volunteers (PCVs) represent a group that could be extremely useful in the transfer and development of such technologies. They have the necessary outreach from their living and working with grass-roots people, and in some cases they have the necessary skills. (159) Programs such as the Peace Corps Energy Program (158) and the Peace Corps Partnership Program (160) are activities the Peace Corps has been involved in which could include materials development. Connecting PCVs with universities has been mentioned (27) as a way of improving their efforts, giving them the technical and research support now available primarily through VITA's volunteers. (161) (The Peace Corps published Technical Notes during the 1960's, giving the Volunteers some technical support, but for reasons unknown to the author, discontinued it before the author's Peace Corps service.)

Organizations which provide funding for renewable materials development or related activities have included the Ford and Rockefeller Foundations (27), AID and A.T. International, and the USDA's Agricultural Research Service (ARS). While the USDA's ARS has primarily a domestic mission, the agency's expertise could be applied internationally through its Office of International Cooperation and

Development, as well as the International Programs Division of its Graduate School. However, ARS budget cuts proposed in 1979 (147) -- especially in the area of post-harvest technologies -- may severely limit all of the ARS's work. AID has long been active in the field of AT for renewable resource utilization, although some of its activities have gone by other names and few in the specific area of this thesis (162), and will likely continue to be a major focal point for U.S. financial support of such programs. A.T. International, funded primarily by the U.S. government, has a small budget relative to AID (155), but one that is larger than most AT groups; it could play a significant role in supporting the information dissemination and extension aspects of the initiatives listed in Chapter 4.

Recently, an organization was proposed for the purposes of strengthening the capacity of developing countries to solve their problems through scientific and technological innovation, fostering research on problems of development, and facilitating scientific and technological cooperation with developing countries. (163) This organization, the Institute for Scientific and Technological Cooperation (ISTC),* may be the most promising organization for funding and support of research and development of appropriate technologies** for building and other materials from agro-wastes and natural fibers. The proposal to establish the ISTC resulted from long discussions on how to remedy the U.S.'s deficiencies in the use of science and

*Previously called the Foundation for International Technological Cooperation.

**Written into ISTC creating legislation (163) was the requirement that research supported by ISTC should emphasize labor-intensive or non-unemployment/-underemployment generating technologies. (163)

technology in its foreign aid program, especially the decline in scientific and technical specialists within AID, the increased demands upon the remaining specialists for solutions to immediate problems, and the requirement of contract procedures which are not simple and flexible enough to allow for large-scale use of developing country individual experts and non-government institutions. (164, 165) Of equal import was the realization that few of the complex problems which plague the development process yield to solutions based primarily on technology transfer because transferred technologies cannot solve problems once and for all; technology transfer must be a constant process of growth and development. (164)

The ISTC proposal marks an effort on the part of the United States to establish "a genuinely collaborative" relationship (165) with developing countries. It was proposed to be separate from AID, but an "equal" with AID in a parent organization, the U.S. International Development Cooperation Agency, established by the Carter Administration as part of Reorganization Plan Number 2 of 1979. (163, 166) To help the ISTC achieve its goal of being "a genuinely collaborative" organization, a Council on International Scientific and Technological Cooperation, a 25-member body with up to a third of these members from foreign countries, would be created to advise the director of the ISTC on policy, programs, planning, and procedure, and which must be consulted by the ISTC director with respect to changes in these, as well as for recommending approval/disapproval of programs or initiatives which cost over $500,000 or which last over two years. (163)

Among the "eight to ten" (164) problem areas proposed for the ISTC's initial efforts are three which overlap with the subject of this thesis: 1) Increasing agricultural productivity and rural income; 2) Environmental protection and natural resource management; and 3) Non-agricultural employment. In addition, there may be scope for research and development of materials from agro-waste in conjunction with research into the use of biomass for energy under the proposed ISTC's "energy planning and new energy supplies area." (164) (See Section 4.2.1.2).

As of this writing, there is considerable uncertainty about the future of the ISTC: In the fall of 1979 the Senate refused to authorize appropriations for the ISTC. (167) Senate objections to the ISTC are based in part upon the belief that "[t]here is no dearth of research and training with respect to [U.S.] development programs" (167) within both AID and the multi-lateral organizations in which the U.S. participations. This belief conflicts with other views (19, 27, 165).

Although the National Science Foundation (NSF) has a legal mandate for collaborative international research, activities in or with developing countries have not been a major focus. (27) However, the NSF has developed a plan to support an experimental program in AT domestically which could provide the basis for future international collaborative efforts in appropriate technology. (19)

5.2.2 Developing Country Organizations

The success of the initiatives in appropriate technology for building and other materials from agricultural wastes and natural fibers will depend very heavily upon the developing countries themselves and the effectiveness of their policies and organizations. (19, 168) Papers associated with UNIDO's Forum on Appropriate Industrial Technology (New Delhi/Anand, India, November 20-30, 1978) and other UN conferences (47) indicate that a considerable amount of activity is going on in this area. Table 5.2 lists some of the organizations in developing countries which could participate in such efforts. Local institutions in developing countries with expertise in renewable resource materials need more support and international recognition for their efforts.

As with Table 5.1, the listings in Table 5.2 are not likely to be comprehensive. Much of the developing country work goes on locally and does not enter international information channels accessible by this or the Principal Study. The preponderance of information from India and Southeast Asia may reflect information sources available to this study while excluding what is happening in areas not represented. This may be especially true of those areas with an international language other than English.

Those DC organizations listed in Table 5.2 can be categorized as government organizations, universities, and research institutes. In addition, there are a number of other types of organizations including appropriate technology and private organizations.

<u>Government organizations</u> in DCs cover a range of organizational types -- laboratories, research institutes, ministries, and commodity authorities -- in a wide variety of resource/materials areas. Such organizations are highly visible and have an important presence in most DCs; in specific areas, some are very active and are making important contributions. The most striking example is the

Central Building Research Institute (CBRI) in Roorkee, India, which has been active in applied research on the use of local materials in construction since 1947. (169) In addition to its varied R&D projects, the CBRI has engaged in extension efforts and widespread publicity* to give their developments maximum exposure. Simplified licensing procedures serve to protect users of the technologies. Along similar lines, but at a smaller scale, is the work of the Ghana Building and Road Research Institute in Kumasi. In many developing countries, such laboratories and institutes are frequently under the aegis of a parent organization such as the Indian, Pakistani, and Ghanaian Councils of Scientific and Industrial Research, the Applied Scientific Research Corporation of Thailand, or Sri Lanka's Ceylon Institute of Scientific and Industrial Research. Such parent organizations operate closely with their government in a manner similar to the NAS and NSF in the U.S. Other developing countries coordinate R&D efforts through various ministries, usually the agricultural ministry, or through the prominent, state-supported, universities.

Universities have been active in many of the residue-material areas in some developing countries. The University of Science and Technology (UST) in Kumasi, Ghana has collaborated with Washington University's CDT on timber housing systems. (170) The UST's Technology Consultancy Centre is an organization, similar to others in developing countries, which has the capabilities for both R&D and extension. In a number of developing countries, universities are

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*For examples, see refs. (8, 66, 92, 105 and 108).

conducting similar research on specific residues and products; in this area, facilitating technical cooperation among developing countries (TCDC) may reduce duplication and lead to quicker results. (168, 171)

While it is doubtful that such university involvements extend to all DCs, there are a number of institutions which have international reputations for work in this area and could serve as regional resources. In addition, some universities are establishing interesting new activities like the Research Centre for Applied Science and Technology (RECAST) at Tribhuvan University in Kathmandu, which was established with the objective of studying and developing different levels of alternative technologies in many areas, including natural product development, construction materials, and post-harvest technologies. (172) Similar activities include the Technology Development and Advisory Unit (TDAU) at the University of Zambia, ASTRA (Application of Science and Technology to Rural Development) at the Indian Institute of Sciences (69), and the Centre for Applied Studies in Development at the University of the South Pacific in Fiji. (173) These universities are involved with rural peoples and provide a framework for applying science and technology for their benefit. Clearly, earlier accusations (19, 27) that universities are aloof from development problems are no longer universally valid. Some have made significant contributions and have fashioned frameworks for expanding such contributions as their capacities grow and demands upon them increase.

Appropriate technology organizations have been expanding in recent years in many developing countries, and a number are active in agro-waste utilization for food, feed, and fuel, and could perhaps be used in the development and extension of agro-waste materials and technologies for their production. For example, the South Pacific Appropriate Technology Foundation (SPATF), established in Papua New Guinea (PNG) two years ago, maintains a central library, answers requests similar to VITA, and is establishing AT centers in PNG. In addition, SPATF has set up a Village Industry Centre to promote business activities applicable to rural conditions and materials. (174) Similar is the Appropriate Technology Development Organization (ATDO) in Pakistan, considered by some to be one of the most active supporters of AT in the Third World (69), which is developing new products from local resources, including paper from banana plants. ATDO funds research both inside and outside Pakistan. Other organizations, such as the Arusha Project in Tanzania and Centro de Desarrollo Indegrado E. Investigaciones Tropicales ("Las Gaviotas") in Colombia, follow a similar model and have done some agro-waste/natural fibers materials research. (69) While some AT organizations in DCs are government related, some are university affiliated or private; many are connected formally or informally with AT groups in the U.S., U.K., France, and Japan.

The most prominent of the <u>other organizations</u> in developing countries are the international research institutes such as the International Rice Research Institute (IRRI) in the Philippines, the International Institute of Tropical Agriculture (IITA) in Nigeria, the International Center for Tropical Agriculture (CIAT) in Colombia, the International Potato Center (CIP) in Peru, and the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) in India.

IRRI has been involved in some of the research into materials from rice hulls. Judging from the FAO survey (6, 78), the other organizations have had little or no involvement in technologies for the production of agro-waste/natural fiber materials, but contain a wealth of information on the properties of their specific crops which could provide the take-off point for materials research. Regional research organizations, such as the Asian and Pacific Coconut Community in Indonesia, have been more involved in materials research.

Along with these research and development organizations -- government, university, AT, international research centers -- many others could contribute to the implementation of agro-waste materials technology at grass-roots level. These include small businesses or cooperatives such as rice millers, PVOs, missionaries, entrepreneurs, and as mentioned in the U.S. section, the Peace Corps and similar organizations like the U.K.'s VSO (Voluntary Service Overseas), Australia's ASA (Australians Serving Abroad), and New Zealand's VSA (Volunteers Serving Abroad).

5.2.3 Other Organizations: National and International

An important organizational resource in appropriate technology for agro-waste and natural fiber materials development consists of private and national organizations in other developed countries and international organizations which have been active in the area. These organizations are discussed because there are a number of them involved in R&D for these technologies; working with these groups may be more worthwhile than trying to duplicate their efforts. Additionally, a number of these developed country organizations have ties with developing country organizations. Some of these organizations are listed in Table 5.3, and again it must be emphasized that this list is only partial, and cannot be considered comprehensive. Communications are channeled by the language used; the use of an international language other than English may have kept knowledge of some organizations and their capabilities and activities from this study.

Appropriate technology organizations in such countries are growing as rapidly as in the U.S. and the developing countries, and they have liaison networks with AT organizations in both the U.S. and DCs. Included in these organizations are CECOCO in Japan, which has been developing food and cottage industry technologies since 1916 and maintains its own farm for testing and training (69), and Intermediate Technology Development Group (ITDG), founded by E. F. Schumacher, in the United Kingdom. ITDG was involved in the development of some of the technologies discussed in Chapter 3. Other such organizations which have the potential to help in the research, development, and/or dissemination of appropriate technologies for agro-waste/natural fiber materials are the Brace Research Institute of McGill University in Canada, the Group de Recherche Sur Les Techniques Rurales (GRET) in France, Stichting Technische Ontwikkeling Ontwikkelings Landen (TOOL) in the Netherlands, and the Interdisziplinäre Projektgruppe fur Angepasste Technologie (IPAT) in Berlin. GRET and IPAT, in their responses to the ATRRU Study mailings, indicated their interest in research in this direction. The Italian organization CICSENE has been active in work on building codes for some areas in

Africa which may be of use for developing building codes which permit the use of agricultural residues. (69)

Government organizations in other developed countries include the Australian CSIRO (Commonwealth Scientific and Industrial Research Organization) and the TPI (Tropical Products Institute) in England (listed in Table 5.3) and the Netherlands Organization for Industrial Research (TNO). (6, 69, 78) Additionally, the agricultural ministries in these countries have potentials similar to our own USDA. Besides these organizations, other developed countries have international development research organizations similar to the U.S'. ISTC. Some of these are Canada's International Development Research Centre (IDRC), Sweden's Swedish Agency for Research Cooperation with Developing Countries, and the United Kingdom's Ministry of Overseas Development (the parent organization for TPI).

Developed country universities are also joining the move towards the development of appropriate technology for renewable resource utilization, as two of the listings in Table 5.3 show. Delft University in the Netherlands, after answering requests for technical assistance for over five years, has established a formal organization to foster cooperation, the Center for Appropriate Technology (DUCAT). Although DUCAT has a number of on-going projects in developing locally available building materials, none were found which dealt with agricultural wastes or natural fibers. (44, 175, 176) There is a large number of developed country universities involved in research into agro-waste/natural fiber utilization (6, 78), although most of that research is not on materials from these resources.

Of the corporate organizations listed in Table 5.3, Cor-Tech Research, Ltd., of Vancouver, B.C., Canada is quite prominent. Cor-Tech has been involved in the development of panels and boards made from rice husks and other wastes using labor-oriented technologies. (6, 78, 79)

In addition to these national organizations, there are significant international organizational resources outside of the U.S. which can contribute to and/or cooperate with developing countries' organizations in the development of appropriate technologies for building and other materials from agro-wastes and natural fibers. The Food and Agricultural Organization (FAO) of the United Nations has been involved in efforts to develop panels and boards from wastes since at least 1957 (6, 7, 152), and has conducted worldwide surveys of production capacity and technological developments in agro-residue technology. (6, 78, 132, 152) The United Nations Industrial Development Organization (UNIDO) joined these efforts in 1970, as realization of the industrial problems inherent in the use of agricultural residues for panel manufacture became widespread. (7, 38, 56, 131) UNIDO has also been a supporter of appropriate technologies in many fields, including processes which use agro-wastes/natural fibers. (30, 32, 66, 74, 76, 87, 102, 106, 114) Along with these FAO and UNIDO efforts are those of the UN Secretariat's Department of Economic and Social Affairs and the UN Economic and Social Council's Committee on Housing, Building and Planning and Committee for Industrial Development. (48, 87, 172, 177) It would seem that the activities of the UN and its specialized agencies confirm the points made in Chapter 2.

The development and implementation of appropriate technologies for building and other materials from agro-wastes and natural fibers requires efforts from many directions.

Other international organizations with potential in the area of this thesis include the Organization for Economic Cooperation and Development (OECD)* and its various organs like the Development Centre (33) and the Department of the Environment's Road Research Group (4), and the International Bank for Reconstruction and Development (IBRD or World Bank), which has become more involved in appropriate technology in the last few years (56), and has been concerned with natural fibers. (126) Regional banks have followed the IBRD's lead; and non-governmentally-organized bodies such as the International Union of Testing and Research Laboratories for Materials and Structure (RILEM), which has a membership composed of 250 building research laboratories in 75 countries, and conducts and shares results of research on the properties of construction materials. (178)

5.3 MECHANISMS FOR INITIATIVE IMPLEMENTATION

Implementation of the initiatives defined in the previous chapter depends upon the existence of a variety of mechanisms.** In determining what mechanisms may be needed, three tests questions are useful; if the answer to one or more of the questions is "no", efforts will be needed in that area:

"(1) Does legislation and organizational infrastructure exist in the U.S. to support U.S. initiatives in

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*The OECD has 24 member countries. (33) With the exception of Turkey, the member countries are industrialized nations of Europe, North America, Australasia and Japan.

**For a definition of mechanisms, see Section 1.3.3.6.

appropriate technology for renewable resource utilization of direct benefit to developing countries?

(2) Do adequate arrangements and linkages exist for cooperative efforts between U.S. and developing country organizations?

(3) Is the financial support base adequate?" (19)

5.3.1 Legal, Organizational, and Financial Support Base

In a study of the role of U.S. universities in science, engineering, and agriculture (27), Washington University's Center for Development Technology reviewed the more general legislative mandates for American involvement in science and technology for development. Based upon that review and succeeding developments, it is thought that with the establishment of the Institute for Scientific and Technical Cooperation (ISTC) (163) there would be both a legislative mandate and an organizational infrastructure in the U.S. government for supporting the initiatives; without ISTC such support is doubtful.

Arrangements and linkages exist for cooperative efforts, as was shown in the discussion of U.S. organizations in Section 5.2.1, and in the above-mentioned CDT study. (27) However, in the literature review and in discussions with participants in the ATRRU Study's VITA-CDT Solar Drying Panel (19), it became obvious that such arrangements and linkages are few, far between, and intermittent in the subject area of this thesis. More and continuing efforts such as those occasionally undertaken by Washington University's CDT (10, 115, 135, 139, 153), Lehigh University, (154) and the East-West Gateway Center at the University of Hawaii (69) are needed. Additionally, U.S. domestic mission-oriented government agencies like

USDA's ARS could have their relevant efforts (Table 5.1) at least disseminated, assuming financial support for expansion is not available.

In sum then, there appears to be no need for a new policy framework or legislative mandate within the U.S. government to carry out the proposed initiatives, assuming the ISTC's successful operation. As noted in the above-mentioned CDT study (27), linkages and arrangements have existed, at least intermittently. Such contacts may need strengthening through increased and continuous use, and, perhaps, more diversification in their scope. The question which remains to be answered is the one regarding funding. As mentioned in the Principal Study, an analysis of how much money is currently being spent by the U.S. for appropriate technology for agro-waste materials has not been undertaken because such data are extremely difficult to obtain. (48)

The initiatives defined in the previous chapter are quite general, involving research, development (design, testing, and extension/information dissemination) and needs analysis. Spending for R&D on all the topical areas of the Principal Study was estimated at one million dollars or less annually (48); only one of those five areas is being considered in this thesis. U.S. resources devoted to R&D efforts in this area alone could be increased by an order of magnitude without any severe budgetary strain, and with good effect. But the difficulties of obtaining such a level of minimum funding for areas which have the potential for improving the conditions of the rural DC poor cannot be overlooked. ISTC's creation will not mean that much more money for development; rather, AID's budget ceiling will be reduced to cover programs transferred to the ISTC, possibly at the expense of other AID programs. "Whereas it is always desirable to eliminate [un]necessary or unproductive programs, a lack of adequate funding to support new initiatives could serve to weaken the U.S. position" (48) as far as UNCSTD is concerned. It appears that this same sentiment may hold in the post-UNCSTD world. (168)

5.3.2 Mechanisms for U.S. Developing Country Interaction

A primary factor in the use of AT for renewable resource agro-waste materials for improving the life of the rural DC poor will be the strengthening of those countries' ability to carry out the activities described in the initiatives. A major contributor to this factor is the identification of DC organizations and individuals that are effective -- for which U.S. assistance will make a difference. The process by which such identification takes place is not well defined, and is likely to be a challenging element of program development and implementation. The developing country institutions listed in Table 5.2 appeared primarily through the literature survey and appeared to be good candidates; they may or may not be ones to focus on for the reasons stated in Section 5.2.2. The literature reviewed in this study may reflect only work that is published (in English); more valuable work may be going on which is unpublished or published in a language other than English.

Many AT organizations hold the view that the poor themselves must be involved in the process of defining needs and selecting or developing technologies to meet those needs, otherwise neither the technology nor the development will be truly appropriate. (69) In compiling the lists in Tables 5.1, 5.2, and 5.3, this view was not used as a selection criteria, although some of the organizations listed do operate along the lines of this philosophy.

Actions by the U.S. on the initiatives defined in Chapter 4 should be in the nature of direct support or indirect support mechanisms for developing country organizations, as summarized in Table 5.4.

5.3.2.1 Direct Support Mechanisms

The most commonly used support mechanism has been that of direct support for developing country organizations. AID and A.T. International use this mechanism in many of their dealings and the proposed ISTC would also make use of it. Because of its responsiveness to political realities (for example, Egypt is currently receiving large amounts of U.S. aid (48)), and because of its flexibility, the direct support mechanism will probably continue to receive heavy emphasis. In addition, the process of requesting and obtaining such support will involve developing countries in the decision processes of the U.S. initiatives. Such participation is encouraged by Canada's IDRC and similar developed country activities, and it is planned for the ISTC. (163) An example of such a direct support mechanism is the NSF administered SEED program, Scientists and Engineers in Economic Development. The SEED program provides support for individual U.S. faculty's short- or longer-term visits to developing country institutions. (27) The principal such mechanism is AID-funded support to DC institutions, such as their $10 million grant to the Egyptian Academy of Scientific Research and Technology and the Egyptian National

Table 5.4

Mechanisms to Support Developing Country Organizations in Appropriate Technology for Building and Other Materials from Agricultural Residues and Natural Fibers*

- Direct Support to Developing Country Organizations
- Bilateral Agreements Between Governments Implemented Through Government Agencies (Direct Support)
- Support U.S. Organizations' Collaboration with Developing Country Organizations (Indirect Support)
- Support International Organizations Which in Turn Support Developing Country Organizations (Indirect Support)
- Support Regional Centers in Work in the Area. (Direct Support and Indirect Support)
- Create and/or Support International AT Mechanisms/ Networks. (Direct Support and Indirect Support)
- Support Multilateral Developing Country Efforts (TCDC). (Direct Support and Indirect Support)

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*Adapted from Reference (19).

Research Center to "enhance the capacity of Egypt's institutions to develop and manage applied science and technology." (162)

A second direct support mechanism involves bilateral, and conceivably multi-lateral, agreements between governments which are implemented through government agencies. Because it is a direct process, this mechanism can be used to bring out matching funds which serve as an earnest of developing country desires as well as being a statement of our government's policies. A recent example of such an agreement in the area of agricultural materials is the agreement with the United States of Mexico (EUM, Mexico) to combine part of the U.S.'s $30 million guayule rubber plant R&D program with Mexico's guayule research and development efforts. This agreement resulted from President Carter's trip to Mexico in early 1979, and could prove as much of a benefit to the U.S. as to Mexico: much more processing research has been done in Mexico, and much of the guayule genetic stock is located in Mexico. The Agencies involved are the NSF in the U.S. and Consejo Nacional de Ciencia Y Technologia (CONACYT) in EUM. (48, 179) The U.S.-India Subcommission on Science and Technology is another such mechanism serving to implement bilateral agreements. (27, 48) Bilateral agreements usually involve support from both sides, and are sensitive to political considerations. Some of the direct institutional supports mentioned earlier may also involve specific bilateral agreements between governments where existing diplomatic agreements make no allowance for, or preclude, direct support to non-governmental institutions.

5.3.2.2 Indirect Support Mechanisms

Indirect support mechanisms involve the use of intermediate organizations as middlemen between the U.S. government and the developing country governments. The indirect support mechanisms listed in Table 5.4 call for the use of domestic and/or international intermediaries. Domestically, there are a variety of organizations which have functioned in this fashion, with universities, an AT organizations, and private research labs as prime examples (see Table 5.1). The extensive U.S. university contacts in international S&T were well documented in the study completed by Washington University's CDT last year. (27) AT organizations and private labs involvements were discussed earlier. Concern has been expressed in Congress and elsewhere (180), over the frequently high proportion of funds for these mechanisms which is spent in the United States rather than in developing countries. In response, ISTC plans have called for the allocation of 75% of their funds for direct overseas expenditures. If policy pronouncements calling for such collaborative support are to be executed, however, it will be essential that funding support for U.S. organizations not be withheld: as much potential benefit can accrue to the domestic organization and the country as to the developing country organization. Neither should be overlooked.

International organizations loom as potentially very important in the development of appropriate agro-waste/natural fiber material technologies. Part of the reasons for this stem from the strong interest shown and experience gained to date by several UN agencies (6, 30, 32, 35, 38, 47, 48, 78, 79, 102, 171), the OECD (4, 150), and to a lesser extent the World Bank. (126) Further, there is considerable interest among developing countries (and in the U.S. Senate (167)) for facilitating much of UNCSTD's initiatives through the UN system, over which they feel they have more influence and control. (81, 182) On the other hand, some prominent individuals in the S&T for development community feel that there are limits to multi-national organizations like the UN, and that mechanisms which involve these organizations may be less appropriate than bilateral mechanisms. (183)

Examples of possible support mechanisms for U.S. organizations' collaboration with developing country organizations in the research and development of appropriate agro-waste materials technology are: 1) BIFAD, the Board for International Food and Agricultural Development, which was created under Title XII of the International Development and Food Assistance Act of 1975. (27) Although the major intent of BIFAD is the provision of an expanded role for certain U.S. universities in helping solve the critical food problems of DCs, a part of this solution, as noted in Sections 2.4 and, especially, 2.5.4, involves the improvement of employment prospects in rural DC areas. Production of materials from agro-wastes could conceivably be included in BIFAD's research efforts. 2) The AID-sponsored programs at the Georgia Institute of Technology, and the Partnership for Productivity which helps rural DC small businesses by supplying user-oriented technical data. (AID also supports some of VITA's similar activities.) (162) And, 3) Section 211(d) of the Foreign Assistance Act of 1966, which provides funds for "assistance ... to research and educational institutions in the U.S. for strengthening their capacity to develop and carry out programs concerned with the economic and social development of the less developed countries." (184) Although Section 211(d) is pretty much in disuse, it deserves mention because of its potential use as a mechanism for U.S. collaboration with DC organizations in R&D for agro-waste materials technology.

5.3.2.3 Direct-Indirect Support Mechanisms

Because scientific research is an organized social -- as well as technical -- activity, it requires interaction and successful communication for its successful operation. Most research is a process of converting information; it starts from a given level of background information, and, through research and other information sources, produces new information. During this process, researchers collect information from many different sources besides their own tests; much of this information comes from papers, journals, newsletters, and surveys conducted and disseminated by specialty groups, many with international contacts. (185) The following direct-indirect mechanisms will serve to propagate such communications, as well as foster research.

Support for regional research centers' activities in appropriate technology for agricultural waste and natural fiber materials can provide models and examples for local institutions and serve as a clearinghouse for information of interest to other institutions in the region. Because such regions are likely to have certain crops in common, the centers can become specialists in their particular region's crops, and be a reference source for those centers which, although focusing on their major crops, are in areas which produce (or are able to) the exogenous crops. Examples of such organizations are mentioned in Section 5.2.2. National centers which serve regional needs, like the University of the South Pacific's Centre for Applied Studies in Development (173), also deserve consideration.

Recent expressions of the importance of the creation and support of international, non-governmental, mechanisms for appropriate technology have come from the Winrock Conference on Appropriate Technology, (31) and at several U.N. Forums (48), where an International Mechanism for Appropriate Technology (IMAT) has been discussed. These expressions stress grass-roots involvement accompanied by the integration of R&D with other AT activities like extension and information dissemination. The prevalent feeling among IMAT advocates is that such an organization may be more effective outside of the UN system, yet in cooperation with it. This fits with Wionczek's statements on the weaknesses of international and transnational organizations (183), and with AT advocates' desires to maintain their independence.

The last mechanism recommended, supporting multilateral DC efforts, may provide the most rapid results because research or technologies currently underway in one developing country which have potential exogenous utility or are related to exogenous research, can frequently be transferred more readily to another developing country than can processes from developed countries. (32, 33, 171) Additionally, technical cooperation among developing countries (TCDC) has considerable support within the developing world (168, 186), and it would be politically sagacious to make use of it.

6. SUMMARY AND RECOMMENDATIONS

6.1 SUMMARY

Renewable resources such as agricultural wastes and natural fibers represent developing country resources which may be used to lessen their dependence upon increasingly costly imported materials. Utilizing these resources for building and construction materials is particularly attractive because of the disproportionate share of foreign exchange allotted to the acquisition of these materials in many developing countries. In rural areas, cost constraints are likely to compel the use of building materials based primarily on locally available natural, or modified natural, raw materials. In urban areas, such materials are seldom inexpensive or plentiful, and are frequently incompatible with stricter urban performance requirements, like fire resistance, and urban construction methods and skills. The use of agro-wastes and natural fibers in the building materials industry has been shown to provide an important multiplier effect on both employment and income, and hence may play a dynamic role in development programs. This is particularly important because many current development plans recognize the need to improve employment prospects in rural areas, especially in agricultural off-seasons, and the need to improve the balance of trade through import reduction and/or increased agricultural exports.

A review of available information indicates that only about 10% of current agricultural residue technologies deal with materials production; the majority of agricultural residue technologies deal with food, feed, and energy processes. Most of the materials technologies are untested on a commercial scale. However, the lack of information on commercial uses of agro-wastes and natural fibers may not reflect the relative importance of this activity or the extent to which their utilization occurs, but the relatively limited information sources available to this study.

Even though successful commercial production from agricultural residues and natural fibers has been limited to bagasse, flax and linseed residues, and to European reeds, a number of small-scale technologies show promise for adoption by developing countries. Rice hulls have been used to produce cement in one commercial-scale technology; and as fillers for cement blocks and panels, for particleboards, and for plastics as well as a lightweight aggregate for concrete in laboratory tests. Both raw and carbonized rice and coconut husks have been demonstrated to be good water filtration materials. Coconut husks may be utilized to produce particleboard with better rot and insect resistance, and with much less resin binder than is usual. Coconut pith has good thermal insulation properties and may be used as an expansion joint filler and as an additive to rubber for an automotive gasket material. Sugarcane bagasse may be used in small-scale processes to produce particleboard and as a filler to produce inexpensive roofing materials. Candidates for natural resin adhesives and adhesive extenders from agricultural wastes have been identified but few have been commercialized. A notable exception is a paper glue produced from cassava starch and plantain alkalis which was reported to meet most of Ghana's need for glue. A number of agricultural residues and natural fibers have been identified as acceptable paper pulp materials although processes need development for wide-scale commercialization. Many natural fibers have been shown to be acceptable reinforcement for concrete panels at several production scales.

Many of these technologies are summarized in Tables 3.3 and 3.4. The board-making potential of a number of agro-wastes and natural fibers are summarized in Table 3.3. Although this table was prepared without regard for process scale, it offers an indication of resource potentials. The specific technologies discussed in this thesis are summarized in Table 3.4, which shows the raw materials and the uses to which they have been put.

There are a variety of organizations and mechanisms which may be utilized to conduct research on and development (including financial, technical, and administrative extension) of appropriate technologies for building and other materials from agro-wastes and natural fibers. Organizations summarized in Tables 5.1, 5.2, and 5.3 range from U.S. and other developed country universities, government laboratories, private research labs, and appropriate technology organizations to developing country universities, etc. Mechanisms, the linkages, programs, or legislation by or through which such organizations may be utilized, are summarized in Table 5.4; they range from the provision of support directly to DC organizations to the support of cooperative research between U.S. and other developed countries on the one hand and developing country organizations on the other, and include support for the efforts of the UN specialized agencies.

6.2 RECOMMENDATIONS

6.2.1 Research and Development Initiatives

There appears to be a wide variety of technical approaches to the utilization of agro-wastes and natural fibers as substitutes for the types of materials produced from costly, non-renewable resources. The research and development initiatives recommended in Chapter 4 and summarized in Table 4.1 represent some promising avenues for increased use of agro-wastes and natural fibers in building and other materials. Included in these initiatives are: 1) assessment of agro-waste and natural fiber types and quantities available for collection and use; 2) support for centers which collect, evaluate, and disseminate information on agricultural residue/natural fiber materials technology; 3) development of composite materials which utilize agricultural wastes and natural fibers as fillers, veneers, etc.; 4) development of binders and extenders for synthetic binders from agricultural products and wood; 5) development of improved preservation treatments and improvements in plant physical properties to improve their performance; and 6) work on developing the hardware and software necessary to overcome collection, storage, and supply problems. While these initiatives were prepared to describe ways in which the United States could participate in the development of agro-waste/natural fiber materials in DCs, some, if not all, of the initiatives could be undertaken by developing countries themselves, or by other developed countries.

6.2.2 Related Issues

That much more work needs to be done in the area of agro-waste and natural fiber materials is clear from this study. In addition to the R&D efforts for product and technology advancement discussed above there is a broader set of related issues requiring investigation. Six avenues are recommended for initial consideration.

First, the production of materials from agricultural wastes and natural fibers needs to be studied in conjunction with the other uses for such biomass. Efforts to give more attention to agro-waste/natural fiber materials production will need to face the questions of supply discussed in Section 4.5.3 and competition from other potential uses. These other uses include energy production (biogas, pyrolytic fuels, and direct combustion), feed and food products, chemical products, and traditional products. Because most plants yield more than one product (e.g. the rice plant yields food, an ingredient of cement, a pulpable straw, bedding and thatching, and feed), the amalgamation of materials research with research into these other uses could augment materials research as well as help to sort our competing product possibilities.

Second, the availability of biomass raw materials needs to be determined in some detail. As noted in Section 4.5, determinations of the availability of biomass resources need to be made for the many different climatic, geographical, and infrastructural (collection, transport, supply, etc.) situations extant in the world. This information will be useful for the efforts to determine how much of the world's biomass can be used for materials, as discussed above. It will be essential for investors, planners, researchers, etc.

because it will identify areas where agro-wastes are presently concentrated enough to support a processing center and where agricultural extension and specific residue/product research may develop the capacities of marginal areas enough to support a processing center.

Third, the problem of competition from materials produced from biomass grown primarily for materials, and not from wastes, needs resolution if land use is to be maximized. A premise of the discussions in the earlier chapters of this thesis is that if biomass building materials come from the residues of food production, competition for land for materials production is minimized, assuming soil fertility can be maintained. While this author and others (7, 62) feel that residues rather than primary biomass should provide the basis for increased use of renewable resources for building materials, this premise may be affected by the rapid expansion of plantations of fast growing timber species in many developing countries. These plantations are capable of producing high-class, uniform, and relatively low-cost building materials. It is felt (7) that this raw material source may take the advantage in plans for new building materials projects, although this is clearly not possible in many countries where timber self-sufficiency is not feasible in the foreseeable future. (5, 36, 37) If land use is to be maximized, these plantations might best be established on marginal lands not suitable for food production.

While it is too early to predict the effects of the agro-waste/natural fiber materials processes on the increased use of these resources, it is felt (7, 19, 38) that their adoption in new factories will occur to an increasing extent, although probably not as rapidly as primary biomass and non-renewable resource processes are adopted. The employment of small-scale technologies is considered an obvious method for reducing and overcoming many of the problems of waste utilization (7, 19, 38) and allowing for the utilization of the smaller, scattered quantities of these resources. At the same time it is realized that this is not the only solution, that there is no single simple solution to the problem. The time is here to assemble, discuss, and disseminate new ideas and approaches to the problem; probably the most effective way of expanding the production of agro-waste/natural fiber materials is to associate their production with increased food production.

Fourth, information on past - as well as present - capital-saving technologies for the production of materials from natural fibers and agricultural wastes need to be reviewed, updated, and disseminated. The following subjects related to the use of labor-intensive process technologies for the manufacture of agro-waste/natural fiber materials should be included in the development programs of those institutions involved in this field.

This thesis has shown that there are many good designs and methods being developed or used in some areas which may be of use to other areas; based on the points made herein, this indicates a line of study which appears to have received too little attention, which could provide much useful information to future development efforts, and which is consonant with the movement towards increasing the technological cooperation among developing countries (TCDC). Involved institutions should not overlook the wider significance of the methods being used today by the small traditional building materials industries in some developing countries. What may seem obvious or of little consequence in one country may be highly appropriate for adoption in some other part of the world. To accomplish this, records will need to be obtained in the field of all the details of the processes being used now, much as the FAO (6, 78) conducted its survey of current research. In some countries it may already be too late to do this, as, with the progress of industrailization, these methods have passed into the realm of industrial archeology.

Industrialized country institutions have an advantage in these efforts because of their access to records of old methods used, especially those used before automation. These efforts can fill the gap in the technical literature coming from industrialized countries which causes their journals to be considered of little significance to the people who run small factories overseas - especially in the building materials industry. (187)

Thus, the old methods need to be re-discovered and re-assessed to see what aspects are still applicable to developing countries. In particular, they could be improved upon by the inclusion of modern working procedures and devices; such improvements will be especially useful in areas where the old skills are still available. This process of review of the most relevant of past technologies could be worthwhile even up to the technologies of a few years ago; for example, the straw-pulp mills of the U.S., which had closed by 1976, might be appropriate for developing countries.

<u>Fifth</u>, more economic analyses need to be undertaken. While Huang's economic analysis framework (63) discussed in Chapters 2 and 4 can provide a basis for analyzing the economics of individual projects, no similar framework for macro-economic analysis was identified during the study. The success of projects like Ghana's glue project can lead to

the casual empiricism that biomass use is more beneficial to a nation than, say, importing; this author feels that this will not be valid for all circumstances because of comparative advantages in trade. Analyses are needed to account for the goal of local, agro-waste/natural fiber materials production while at the same time allowing for development goals of maximum employment, etc. A more "holistic" approach to the economic analysis of agricultural development schemes needs to be developed to fully ascertain the real benefits to rural areas from agro-industrialization.

Included in this area is the need for economic analyses of commercialization schemes with the government as investor and its return computed from future income, and other, tax earnings. Such analyses can indicate the best ways for the local government to support the development (deployment) of these technologies.

And sixth, the environmental and health effects from increased biomass use and from biomass processing need to be researched and technologies developed to overcome any harmful effects. Two examples of harmful health effects from biomass processing are the disease bagassosis, which can develop from exposure to bagasse dust, and brown lung disease which can develop from exposure to cotton dust. This avenue for R&D would also include studying the effects of the environment on biomass products. As indicated in Section 3.2.3, potentially harmful chemicals leached out of some bagasse-reinforced panels during their development trials because of the effects of sunlight and rain; coatings to inhibit such effects increase costs. Potential environmental problems may also result because the removal of wastes from the field where it serves as a soil amendment may lower its fertility and increase the potential for erosion.

6.2.3 Future Investigations

While this study discusses appropriate technology for building and other materials from agricultural residues and natural fibers in some detail, there are other avenues which would have been pursued if time and other resources were sufficient. This thesis should be considered a first, pioneering, effort to bring some order and semblence to an emerging field of study and work; omissions may have occurred because knowledge of significant efforts may not have been available to this study. Since this is one of the few works on this subject, two of these avenues will be mentioned as suggestions for future actions.

Because this study relied upon published articles and papers, the limited mailing, and VITA's files, the information gained was not as thorough as it could be if more time and resources were available. A more comprehensive mail survey, with follow-up correspondence and visits would have provided much more and more up-to-date information for the state-of-the-art review, organization listings, and developing country needs and limitations. In addition, a survey which included on-site visits would have overcome many of the obstacles of language, given a better understanding of what, and how much, work is going on which is unpublished, and provided more ideas for, or examples of, mechanisms for implementing the initiatives.

Another path would involve the holding of one or a series of panels on this subject. The preferred option would be a series of panels, held in different parts of the world. In addition to providing much of the additional information mentioned above, such panels would also provide the vehicle for ideas and information exchange among the panel members, and would hopefully provide a broad consensus of the needs and considerations of developing countries on this subject.

7. ACKNOLWEDGEMENTS

It would have been impossible to write this thesis without the assistance, support, and contributions of many people. My thanks and gratitude go to my family for their support and encouragement, and especially my Aunt and late Uncle who helped me to acquire a better understanding of other cultures; to the other members of the ATRRU Study team, especially Professor Robert P. Morgan, who was also my advisor on this thesis, and J. P. R. Falconer for their many contributions incorporated into this thesis; to Ratu Jone F. Radrodro, his family, and my other co-workers in Fiji for their insights into the development process; to my fellow THA students for their friendship and assistance, especially Bobbi Fox, Charlie Clark, and Azzahari bin Hassan; and to Mary Baetz and Donna Williams for deciphering my drafts and typing them.

In addition, I wish to acknowledge the financial support of the Agency for International Development under contract No. AID/DSAN-C-0061 and of the Department of Technology and Human Affairs/ Center for Development Technology and Washington University under the College Work-Study Program.

8. BIBLIOGRAPHY

1. New York Times News Service, "1 Billion More People Projected for the Less-Developed Urban Areas," St. Louis Post-Dispatch, 19 August, 1979, p. 3H.

   Bill Peterson, "The Global Majority, An American Odyssey, Part 1," The Washington Post, May 14, 1978, pp. A1, A18.

2. "Material Resources and Their Conservation," Chemical Technology: An Encyclopedic Treatment, Volume VIII, Barnes and Noble, New York, 1975, pp. 365-401.

3. NRC, Renewable Resources for Industrial Materials, NAS, Washington, D.C., 1976.

4. OECD, Use of Waste Materials and By-Products in Road Construction, OECD, Paris, 1977.

5. Papers for Conference on Improved Utilization of Tropical Forests, May 21-26, 1978, Madison, Wisconsin. Printed by the Forest Products Laboratory, Forest Service, U.S. Department of Agriculture.

6. FAO, Agricultural Residues: Compendium of Technologies, FAO, Rome, 1978.

7. A. E. Chittenden, Historical Outline of Past Research on the Production of Boards From Agricultural Wastes and Future Research Trends, UNIDO, Vienna, 1970.

8. CSIR Technologies in the Field of Agro-based Industries, CSIR, New Delhi, August, 1976.

9. Recommendation #9 of the Africa Regional Meeting of the U.N. Habitat and Human Settlements Foundation, November, 1968.

10. R. P. Morgan and A. T. DiBenedetto, "An Inter-American Program in Materials Engineering -- The Utilization of Indigenous Resources for Low-Cost Materials," in Proceedings of Second Inter-American Conference on Materials Technology, Education Volume, pp. 19-26, Mexico City, August, 1970.

11. Earl Kessler, "A Role for Replenishable Resources in Shelter Programs," FCH Human Settlement Series, FCH, Washington, D.C., January, 1979.

12. Natural Products for Sri Lanka's Future, Report of a Workshop held from 2-6 June, 1975, in Colombo, sponsored by the National Science Council of Sri Lanka and the U.S. National Academy of Sciences, National Science Council, Colombo, 1975.

13. E. F. Schumacher, Small Is Beautiful, Harper and Row, New York, 1973.

14. Edward P. Cliff, TIMBER: The Renewable Material, National Commission on Materials Policy, August, 1973.

15. Kyosti V. Sarkanen, "Renewable Resources for the Production of Food and Chemicals," Materials: Renewable and Nonrenewable Resources, AAAS, Washington, D.C., 1976, pp. 184-188.

16. Central Planning Office, Fiji, Fiji's Seventh Development Plan, 1976-1980, Parliament Paper No. 20 of 1975, Parliament of Fiji, November, 1975, p. 12. The value added by the timber/wood sector is about 10% of that for the agricultural sectors, yet the acreage difference between these sectors is only 2 or 3 to 1. Fiji's silviculture development program, discussed in Chapter 14, shows projected employment in the growing and harvesting of the timber to be around one person per 74 acres (30 hectores). This is considerably lower than agricultural growing and harvesting employment.

17. P. Huybers, "Appropriate Building Methods and Materials in Developing Countries," Appropriate Technology for Developing Countries, Willem Riedijk, editor, Delft University Press, The Netherlands, 1979.

18. Second National Development Plan, January, 1972 - December, 1976, Republic of Zambia, Government Printer, Lusaka, December, 1971; Fiji's Seventh Development Plan, 1976-1980, Parliament Paper No. 20 of 1975, Parliament of Fiji, November, 1975.

19. Robert P. Morgan and Larry J. Icerman, Principal Investigators; with E. S. Andrews, J. A. Chapman, J. P. R. Falconer, H. Herring, J. L. Kardos, C. G. Kick III, E. B. Shultz, Jr., and H. G. Winger; "Appropriate Technology for Renewable Resource Utilization," Final Report prepared for the Agency for International Development, June 1979.

20. Observations by the author during four years (1971-74) in Labasa on the outer large island of Fiji: Cement could be had in the capital, Suva, where it was produced from coral reef material for F$20/ton, while the price in Labasa was over F$40/ton.

21. UN ESA, Science and Technology for Development, UN, New York, 1970.

22. Stefan Dedijer, "The Failure of the 1978 UN Conference on Science, Technology and Development," Offprint Series No. 2, Research Policy Program, University of Lund, Sweden. This was a reprint of an article which appeared in "Science and Social Imperatives" Special Issue of Philosophy and Social Action, Vol. II, No. 102 (1976), pp. 89-96.

23. Joao da Costa, "Statement by the Secretary-General of the Conference at the Opening Meeting of the Second Session of the Preparatory Committee for the United Nations Conference on Science and Technology for Development," Geneva, 23 January - 3 February, 1978.

24. "Science and Technology for Development," U.S. National Paper for the United Nations Conference, 1979, U.S. Department of State, Washington, D.C. 20520, January, 1979.

25. NRC, U.S. Science and Technology for Development: A Contribution to the 1979 U.N. Conference, Department of State, Washington, D. C., 1978.

26. R. P. Morgan, "Robert P. Morgan Reviews U.S. Science and Technology for Development: A Contribution to the 1979 U.N. Conference," Bulletin of the Atomic Scientists, Vol. 35, No. 6 (June, 1979), pp. 55-57.

27. Robert P. Morgan, Principal Investigator, with E. E. Irons, E. A. Perez, T. N. Soule, and Ava Fried, The Role of U.S. Universities in Science and Technology for Development: Mechanisms and Policy Options, Final Report prepared for the National Science Foundation. September 1, 1978. Published by Pergamon Press, New York, 1979, under the title, Science and Technology for Development: The Role of U.S. Universities.

28. Current Literature on Science of Science, Vol. 8, No. 1 (Jan., 1979), p. 2.

29. There is a consensus among economists on the existence of a dualistic structure in most developing countries. This dualistic structure results from the coexistence of two differentiated sectors within the same society, the differences being in the socioeconomic modes of behavior and organization as well as in the technology used. An example of this might be the existence of a small, relatively (to the rest of that society) well paid, labor force employed in the manufacture of, say television components for export, while the remainder of the population is still engaged in subsistence agriculture. For discussions of this, see Marwan Ghandour and Jürgen Müller's article, "A New Approach to Technological Dualism," Economic Development and Cultural Change, Vol. 25, No. 4 (July, 1977), pp. 629-637; and Charles P. Kindleberger and Bruce Herrick, Economic Development, Third Edition, McGraw-Hill, New York, 1977.

30. J. E. Stepenek, Selection, Development and Application of Technologies Appropriate for Social Equity and Economic Growth, Draft Study prepared at the request of the Indian Ministry of Industrial Development under a contract with UNIDO, 23 January, 1974.

31. "Preliminary Report from a Workshop on Appropriate Technology," December 1-5, 1978, Winrock International Conference Center, Morrilton, Arkansas, pp. 9-10. This Workshop was funded by the Office of the U.S. Coordinator, UNCSTD, State Dept., Washington, D.C.

32. "Draft Report of the Technical/Official Level Meeting to the Ministerial Level Meeting," International Forum on Appropriate Industrial Technology held at New Delhi/Anand, India, 20-30 November, 1978, p. 4. Publication ID/WG. 282/124. Cited in Ref. 19, at pages 2-8 and 2-9. It is interesting to note that the report of the Ministerial Level Meetings, in addition to changes in the first two paragraphs quoted, dropped the last paragraph altogether. (ID/WG.282/123, pp. 6-7).

33. Nicolas Jequier, Appropriate Technology: Problems and Promises, OECD, Paris, 1976.

34. C. Peter Timmer, John W. Thomas, Louis T. Wells, and David Morawetz, The Choice of Technology in Developing Countries (Some Cautionary Tales), Center for International Affairs, Harvard, 1975.

35. UNIDO, Building Materials Industry, UNIDO, Vienna, 1969.

36. Ann Kestenbaum, ed., Technology for Development, VCOAD, London, November, 1975, p. 67.

37. Irving S. Goldstein, "Potential for Converting Wood into Plastics," Materials: Renewable and Nonrenewable Resources, AAAS, Washington, D.C., 1976, pp. 179-184.

38. UNIDO, Production of Panels from Agricultural Residues, UNIDO, Vienna, 1972.

39. McGraw-Hill Encyclopedia of Science and Technology, Vol. 14. McGraw-Hill, New York, 1966.

40. Letter from Bernard W. Burgess, Executive Vice President of the Pulp and Paper Research Institute of Canada, to Prof. John Kardos, Washington University, November 17, 1978.

41. CSIR, The Wealth of India-Raw Materials, CSIR, New Delhi. This is an eleven volume work which describes in some detail the plant, animal, and mineral resources found in India. It was produced by the staff of India's Council of Scientific and Industrial Research (CSIR) between 1948 (Vol. I) and 1976 (Vols. X and XI). (See, for example, references 107, 112, and 119). In addition, the CSIR produced a nine volume companion, Wealth of India - Industrial Products over the same period. (see, for example, references 75 and 127.)

42. Lonnelle Aikman, Nature's Healing Arts, National Geographic Society, Washington, D.C., 1977. See also the Foxfire books, 1-5, edited by B. Eliot Wigginton, Anchor Press, Garden City, N.Y., 1972-8.

43. Dr. P. Dunnill, "The Provision of Drugs by Appropriate Technology," Appropriate Technology, Vol. 4, No. 2 (August, 1977, pp. 16-17.

44. "Dutch University Creates Center for Appropriate Technology," Small Industry Development Network, No. 14 (February, 1979), p. 3.

45. Henry J. Rutz, "Ceremonial Exchange and Economic Development in Village Fiji," Economic Development and Cultural Change, Vol. 26, No. 4 (July, 1978), pp. 777-805.

46. Discussions held with Fiji's Ministry of Agriculture staff and with a Fiji handicraft cooperative's staff during the author's service in Fiji, 1971-74.

47. UNIDO has held at least one: The Expert Working Group on the Production of Panels from Agricultural Wastes met in Vienna, 14-18 December, 1970; The UN Secretariat (ESA) held at least one: The Expert Working Group on the Use of Agricultural, Industrial, and Consumer Wastes in Low-Cost Construction, Rio Piedras, Puerto Rico, 9-13 December, 1974; and the FAO/UNEP held a Seminar on Residue Utilization - Management of Agricultural and Agro-Industrial Wastes in Rome, January, 1977.

48. Use of Agricultural and Industrial Wastes in Low Cost Construction, UN Department of Economic and Social Affairs, New York, 1976.

49. Joseph E. Atchinson, "Agricultural Residues and Other Nonwood Plant Fibers," in Materials: Renewable and Nonrenewable Resources, AAAS, Washington, D.C., 1976, pp. 174-8.

50. "Rice Hull Ash Cement ... High Quality, Acid Resisting," ACI Journal, May, 1975, pp. 235-6.

51. UN ECA, "The Status and Problems of Housing and Construction Industry in Africa," presented at UNIDO's Meeting on Prefabrication for Africa and the Middle East, 1972, ID/WG.122/19.

52. A. T. DiBenedetto and R. P. Morgan, "A Proposal to Establish a Cooperative International Program on the Development and Utilization of Indigenous Materials for Low-Cost Housing and Economic Development," Washington University, St. Louis, Missouri, October, 1969.

53. Letters from J. P. R. Falconer to ATRRU Study, dated 24 March, 1979, and 10 April, 1979.

54. See for example "Design in the Tropics, A Draft Manual for Architects in the Developing Countries," The Department of Tropical Studies of the Architectural Association School of Architecture, 36 Bedford Square, London, U.K., 1965.

55. Personal Communications from Philip J. Schneider, Ministry of Works, Fiji, dated 3 January and 19 February, 1979.

56. UNIDO, Industrial Development Survey, UN, New York, 1979, p. 205.

57. See, for example, FAO, The State of Food and Agriculture, 1966, Chapter III, FAO, Rome, 1966; and successive annual issues of this publication.

58. "Alternative Futures -- Application of Science and Technology to North-East Tribal and Hill Area Development," Current Literature on Science of Science, Vol. 8, No. 1 (January 1979), pp. 5-6.

59. Robert F. Kennedy, To Seek a Newer World, Doubleday and Co., Inc., New York, 1968, pp. 92-100.

60. NAS, Tropical Legumes: Resources for the Future, NAS, Washington, D.C., 1979.

61. Allen L. Hammond, "Photosynthetic Solar Energy: Rediscovering Biomass Fuels," Science, Vol. 197, pp. 745-6.

62. Although not specific to materials from agricultural residues, the case of James Michener's Centennial character, Hans "Potatoe" Brumbaugh is relevant to the point being made here: The recent tendency in the U.S., and presumably other industrialized countries, has been to grow what was used rather than to use what was grown; Brumbaugh became a cattle rancher because he grew sugar beets and found that the tops and pulp were good cattle feed, and could be used as such even when sugar prices were low. (My thanks to fellow Fiji Peace Corps Volunteer Garry Huls for reminding me of discussions of this.)

63. Wen-Yuan Huang, "A Framework for Economic Analysis of Livestock and Crop By-products Utilization," American Journal of Agricultural Economics, Vol. 61, No. 1 (February, 1979), pp. 91-96.

64. Köppen and Geiger, Klima der Erde (map), revised by R. Geiger and W. Pohl, Justus Perthes, Darmstadt, 1953.

65. Observations and discussions by the author with the owners/managers of several plantations on Taveuni Island, Fiji; with Northern Division staff of the Fiji Coconut Pests and Diseases Control Board; and with the anti-filariasis campaign in Nasavasavu District, Vanua Levu, Fiji.

66. CBRI, "Appropriate Technologies and Materials for Housing and Building," a background paper presented at UNIDO's International Forum on Appropriate Industrial Technology, New Delhi/Anand, India, 20-30 November, 1978.

67. "Draft Report of the Technical/Official Level Meeting to the Ministerial Level Meeting," International Forum on Appropriate Industrial Technology, UNIDO, New Delhi/Anand, 20-30 November, 1978. Cited in reference 32.

68. The Laws of Fiji, 1967 Edition, Government Printer, Suva.

69. Integrative Design Associates, Inc., Appropriate Technology -- A Directory of Activities and Projects, NSF/RANN, Washington, D.C., 1977.

70. Allen L. Hammond, "Alcohol: A Brazilian Answer to the Energy Crisis," and "Energy: Brazil Seeks a Strategy Among Many Options," Science, Vol. 195 (11 February, 1977), pp. 564-567.

71. "Coconut-the All-around Provider," Development Forum, January-February, 1979, p. 4.

72. This theme recurs in M. K. Garg's "The Scaling-Down of Modern Technology: Crystal Sugar Manufacturing in India," "The Upgrading of Traditional Technologies in India: Whiteware Manufacturing and the Development of Home Living Technologies," Appropriate Technology: Problems and Promises, Nicolas Jequier, editor, OECD, Paris, 1976, pp. 156-188; and in "India-Small Scale Is Not Necessarily Inefficient," Technology for Development, Ann Kestenbaum, editor, VCOAD, London, November, 1975, p. 66.

73. While much of this paragraph was phrased from contributions to the ATRRU Study by J. P. R. Falconer (Reference 53), the same discussion appeared in papers studied by the author during his service in Fiji. The most pertinent of these papers are: 1) Guy Hunter, "Rural Development (Organization and Administration)," Legislative Council of Fiji Paper No. 6 of 1969; 2) Development Committee (Fiji) Paper, "Preparation of the Rural Development Programme," 1 August, 1969; 3) K. K. T. Mara, Chief Minister, Circular Memorandum entitled "Rural Development," File No. 1161/1(TC), 8 August, 1969; and 4) Development and Development Sub-Committee (Fiji) Paper No. P.7/69, "Administration of Funds for Rural Development, Particularly Self-Help Projects Outside Existing Departmental Programmes," 24 November, 1969.

74. UNIDO, "Appropriate Technology for Pulp and Paper Production," Discussion Paper for Working Group No. 10, Appropriate Technology for the Manufacture of Pulp and Paper Products; UNIDO Forum on Appropriate Industrial Technology, New Delhi/Anand, India, 20-30 November, 1978.

75. CSIR. Wealth of India -- Industrial Products, Vol. 6 (M-P), CSIR, New Delhi, 1965.

76. "Pulping Technologies and Requirements and Potentialities of Developing Countries," background paper distributed to Working Group No. 10, Appropriate Technology for the Manufacture of Pulp and Paper Products, UNIDO Forum on Appropriate Industrial Technology, New Delhi/Anand, India, 20-30 November, 1978. (ID/WG.282/17).

77. Fiji Today, 1978, Ministry of Information, Suva, 1979.

78. FAO, Agricultural Residues: World Directory of Institutions, First Revision, FAO, Rome, 1978.

79. FAO, Bibliography of Agricultural Residues, FAO, Rome, 1978.

80. CSIR, The Wealth of India - Raw Materials, Vol. VII, CSIR, New Delhi, 1966, p. 180.

81. "Crops on Reclaimed Alkaline Soils?," Times of India, 22 October, 1979, p. 6.

82. U.S. Patent Nos. 3,951,907 and 4,105,459 (filed 28 July, 1972). Patents applied for in major rice producing countries.

83. D. F. Houston, "Rice Hulls," in D. F. Houston, Ed., Rice: Chemistry and Technology, American Association of Cereal Chemists, 1972. Cited in Reference 19.

84. Report of VITA Panel on Wood Waste and Waste Paper Utilization, May 7, 1976.

85. Chemical Engineering, December 10, 1973, p. 67.

86. David Holmstrom, "Professor Makes Rice-Hull Cement," The Christian Science Monitor, December 7, 1973, p. 1.

87. P. Kumar Mehta, "The Chemistry and Technology of Cements Made From Rice Husk Ash," a paper presented at the UNIDO/ESCAP/RCTT Workshop on Cement from Rice Husks, held in Peshawar, Pakistan, 22-26 January, 1979.

88. P. Kumar Mehta and N. Pitt, "A New Process of Rice Husk Utilization," Proceedings, Fourth International Conference of Rice Byproducts Utilization, Valencia, Spain, 1974.

89. P. Kumar Mehta and N. Pitt, "Energy and Industrial Materials From Crop Residues," Journal Resource Recovery and Conservation, Vol. 2, pp. 23-38, 1976.

90. D. J. Cook, R. P. Pama, and S. A. Damer, "Rice Husk Ash As A Pozzolanic Material, in New Horizons in Construction Materials, Vol. I, 1976, Envo Publishing Co., Lehigh Valley, PA., pp. 431-442.

91. S. S. Rehsi, "Pozzolana Based Binders," Appropriate Technology, Vol. 5, No. 4, February, 1979, pp. 22-23.

92. Marendra Verma, "Materials and Technology for Rural Buildings," Rural Buildings Division, CBRI, undated.

93. 1979 Commodity Year Book, Commodity Research Bureau, New York, June, 1979. p. 93.

94. The CINVA-RAM, a lever operated press and mold box of very simple design and operation, was developed for the manufacture of soil and soil-cement blocks by the Inter-American Housing and Planning Center in Colombia. Since its development, it has been adapted to other materials. It costs approximately $180.

95. F. M. Lauricio, J. O. Siopongco, and Tamolong, "Fabrication of Hollow Blocks from Agri-Forestry Materials for Low-Cost Housing," Appropriate Technology, Vol. 5, No. 2, August, 1978, pp. 18-19.

96. "Agricultural Waste as a Civil Engineering Material," Small Industry Journal, Vol. 7, No. 3, March, 1975, pp. 30-33.

97. D. J. Cook, "Waste Products Utilization - An Investigation of Materials Applications for Rice Hulls," Studies from the School of Civil Engineering, University of New South Wales, Kensington, UNICIV Report #100, December, 1972.

98. B. J. Van der Kamp and A. A. Gokhale, "Resistance of Rice Husk Board to Decay Fungi," Journal of the Indian Academy of Wood Science, Vol. 5, No. 2, July/Dec. 1974, pp. 106-7.

99. R. C. Vasishth, "Manufacture of Composite Boards from Rice Husks Using a Batchwise, Labour Oriented Plant," 1974, cited in 98 above. "Project Proposal: Rice Husk Board Manufacture in Malaysia" by the same author, 1974.

100. "ITDG Makes Olympics?," Appropriate Technology, Vol. 5, No. 3, November 1978, p. 30.

101. Richard J. Frankel, "The Design and Operation of a Water Filter Using Local Materials in Southeast Asia," Appropriate Technology: Problems and Promises, Nicolas Jequier, editor, OECD, Paris, 1976, pp. 238-52.

102. UNIDO, Technologies from Developing Countries, No. 7 in the UNIDO Transfer of Technologies Series, UNIDO, New York, 1978.

103. Ben S. Bryant, "Corrugated Roofing Panels from Agricultural Residues," Appropriate Technology, Vol. 4, No. 4 (February 1978), p. 26-28.

104. "Coconut Husk Chipping Machine," Building Practice, Vol. 4, No. 10 (October, 1973), p. 14.

105. CBRI, "Corrugated Roofing Sheets from Coir Waste or Wood Wool, CBRI Technical Note #68, 2nd Revision, January 1978.

106. Hakan Persson and Ake Skarendahl, "Sisal Fibre Concrete for Roofing Sheets and Other Purposes," Background Paper for Working Group No. 5, Appropriate Technology for the Production of Cement and Building Materials; UNIDO Forum on Appropriate Industrial Technology, New Delhi/Anand, India, 20-30 November, 1978.

107. CSIR, The Wealth of India -- Raw Materials, Vol. II, CSIR, New Delhi, 1950.

108. R. K. Jain and Joseph George, "Coconut Pith Cement for Thermal Insulation," CBRI Building Materials Note #9, September, 1968.

109. "Coconut Water as an Intravenous Fluid," South Pacific Bulletin, Vol. 22, No. 4 (4th Quarter, 1972), p. 17.

110. George B. E. Schuler, "Uses of Coconut Products," Modern Plastics, Vol. 10, No. 1 (June, 1946), pp. 118-9.

111. "The All-Coconut House," FIJI, Vol. 1, No. 4 (September-October, 1978), p. 2.

112. CSIR, The Wealth of India -- Raw Materials, Vol. IX, CSIR, New Delhi, 1972.

113. "Fiji's Search for Energy," FIJI, Vol. 1, No. 3, July-August, 1978, p. 10.

114. "Draft Report of Working Group No. 10, Appropriate Technology for Paper Products and Small Pulp Mills" UNIDO Forum on Appropriate Industrial Technology, New Delhi, India, 20-25 November, 1978.

115. George L. Ball, et al., Development of Low-Cost Roofing from Indigenous Materials in Developing Countries, Monsanto Research Corp., Dayton. Second Annual Report, 18 December, 1975.

116. G. L. Ball, III, A. M. Usmani, D. W. Werkmeister, and J. P. R. Falconer, "Development of Low-Cost Roofing from Indigenous Materials in Developing Countries," Final Report to USAID, Monsanto Research Corp., Dayton, Ohio (Washington University, Center for Development Technology contributions on Subcontract to J. P. R. Falconer).

117. D. N. Daruvalla and V. G. Kamath, "Utilization of Sugar Industry Waste: Mineral Wool from Filter Press Mud," Shri Ram Institute for Industrial Research, Delhi, India, 1952.

118. J. W. Powell, Appropriate Technology in India, University of Science and Technology, Kumasi, Ghana, 1978, p. 29-30.

119. CSIR, The Wealth of India -- Raw Materials, Vol. VI, CSIR, New Delhi, 1962, pp. 286-7, 292, 323-5, and 353.

120. A Capell, A New Fijian Dictionary, Fourth Edition, Government Press, Suva, 1973, p. 357.

121. B. A. Ntim and J. W. Powell, "Appropriate Technology Consultancy Center," Appropriate Technology: Problems and Promises, Nicolas Jequier, Editor, OECD, Paris, 1976, pp. 276-295.

122. Sally Holterman, Intermediate Technology in Ghana, ITDG, London, August, 1979, pp. 24-8.

123. Anthony Hopkinson, "Small Scale Paper Making," Appropriate Technology, Vol. 4, No. 2 (August, 1977), pp. 4-5.

124. Patents include Nos. 2, 196, 277 (April 9, 1940); 2,645,587 (July 14, 1953); 3,301,800 (January 31, 1967). See also: "Low-Cost Molding Material from Agricultural Wastes," by McElhinney, Clark, and Lynch in Modern Plastics, Vol. 2, No. 10 (March, 1939).

125. S. M. Singh and L. K. Aggarwal, "Binder for Many Wastes," Research and Industry, Vol. 22, No. 4 (1977), pp. 245-6.

126. Enzo R. Grilli, The Future for Hard Fibers and Competition from Synthetics, World Bank Staff Occasional Papers Number Nineteen, Johns Hopkins University Press, Baltimore, 1975.

127. CSIR, The Wealth of India -- Industrial Products, Vol. V (I-L), CSIR, New Delhi, 1960, pp. 21-23.

128. CSIR, The Wealth of India -- Industrial Products, Vol. IV (F-H), CSIR, New Delhi, 1957.

129. CSIR, Wealth of India -- Raw Materials, Vol. VI, CSIR, New Delhi, 1962, pp. 448-469.

130. Cyril G. Jarman, "Banana Fibre in Rural Industries," Appropriate Technology, Vol. 5, No. 1 (May, 1978), pp. 25-6.

131. Hans Augustin, "Annotated Bibliography on the Utilization of Agricultural Residues and Non-Wood Fibrous Materials for the Production of Panels," UNIDO, Vienna, 14 May, 1973. (ID/WG.83/16).

132. FAO, "World Survey of Production Capacity," FAO Committee on Wood Based Panel Products, December, 1970. Cited in Reference 7.

133. Frank M. Gentry, The Technology of Low Temperature Carbonization, Williams and Wilkins, Baltimore, 1928, pp. 5, 148-9.

134. "Wheat - Puffed and Carbonized - as an Aggregate," in Concrete Construction, November, 1971. Cited in Reference 19 at 7-37.

135. In 1971, Washington University's Center for Development Technology experimented with the "carbonized wheat" approach, using non-cereal plant materials (bamboo and reeds). This work was directed at finding suitable low-cost, lightweight and environmentally inert fillers for sandwich panels having matrices of various foams, the end-use being for tropical roofing components. Increased resin costs caused the foam work to be abandoned, but the production of carbonized bamboo particles worked well at laboratory scale. Cited in Reference 19 at 7-37.

136. J. P. R. Falconer, "Report on Field Trip to S.E. Asia - February 15 to March 20, 1974," for USAID/Monsanto Research Corporation/Washington University Roofing Research Project (Subcontract AID 7312).

137. See also reference 6, pp. 142-180 for some wood wastes technologies, and "Timber: More Effective Utilization," by Edwin C. Jahn and S. B. Preston, in Materials: Renewable and Nonrenewable Resources, AAAS, Washington, D.C., 1976, pp. 163-7.

138. Encyclopedia of Chemical Technology, Second Edition, Vol. 10 (1966) and Vol. 12 (1967). New York: John Wiley and Sons.

139. In 1975, at Washington University's Center for Development Technology, a small laboratory experiment was directed at the fire protection of palm leaves (the Nypa Palm, from the Philippines). It was found that the difference between wood and the thatching leaves made it difficult to transfer the wood technology directly to leaves, primarily because the waxy cuticle of the leaf made penetration difficult. Gaseous treatment appeared to be a more viable alternative. Both chlorine and bromine, as gases, have been used as fire treatments, although, being hazardous materials, they would be difficult to adapt for use in rural situations. Ammonium sulfate, a cheap and available fertilizer, has been used to fire-treat wood and paper and as an insecticide. The Central Building Research Institute, Roorkee, India, has reported experiments with di-ammonium phosphate and sodium fluoride for combined fire, insect and fungal protection; flame spread was eliminated, but leaching problems required the application of additional weatherproofing. Cited in Reference 19 at 7-35.

140. CSIR, The Wealth of India -- Raw Materials, Vol. X, CSIR, New Delhi, 1976, pp. 299-306.

141. The author, while in Fiji observed the destruction of almost the entire village of Dama, Bua Province, because a "simple" fire spread from a kitchen on the wind and through the dry grass prevalent in the area.

142. Personal communication, D. L. Davies of the Koppers Company, Pittsburgh, PA., to J. P. R. Falconer, 8 June, 1979. Cited in Reference 19.

143. P. C. Cheo and Kenneth R. Montgomery, "The Study of Fire Retardance in Plants," Lasca Leaves, September, 1970.

144. R. Austin, D. Levy, and K. Ueda, Bamboo, Walker/Weatherhill Books, New York and Tokyo, 1970.

145. Wheeler McMillen, New Riches From the Soil: The Progress of Chemurgy, D. Van Nostrand Co., New York, 1946.

146. Letter from the Director of the George Washington Carver Research Foundation of Tuskegee Institute to Professor E. B. Shultz of Washington University, 18 October, 1979.

147. Ralph D. Wennblom, "Big New Budget Cuts for USDA," Farm Journal, No. 8 (June/July, 1979), pp. 17.26. See also the "Opinion" section of the same issue of Farm Journal (on page 68): "Behind Those USDA Budget Cuts."

148. Meeting at USDA-ARS Northern Regional Research Laboratory (NRRL), 28 November, 1979, with E. H. Pryde, L. H. Princen, et. al. of NRRL, and Prof. E. B. Shultz and author of Washington University's Department of Technology and Human Affairs.

149. Fardous Mobarak, Abd-Alla M. Nada, and Yehia Fahmy, "Fibreboard from Exotic Raw Materials -- 1. Hardboard from Rice Straw Pulps," Journal Applied Chemistry and Biotechnology, Vol. 25 (1975), pp. 653-8.

150. OECD, "Development Centre Research Activities, Part II: Proposals for New Research Projects," OECD, Paris, 1 June 1976. (CD/INF(76)3 Part II).

151. From author's observations and discussions with cane farmers and extension agents in Fiji. See also the section on Saccharum in reference 112.

152. UN FAO, "Fibreboard and Particle Board -- Technical Papers and Report of International Consultation on Insulation Board, Hardboard and Particle Board," Geneva, 1957, UNFAO, Rome, 1958. Cited in reference 7 at page 5.

153. R. P. Morgan and J. P. R. Falconer, "U.S. Universities and Developing Countries: Some Experiences with Appropriate Chemical and Materials Technology," paper presented at AAAS Annual Meeting, San Francisco, CA., March 1, 1974. (Available from Center for Development Technology, Washington University, St. Louis, MO 63130). (Cited in Reference 19 at 7-49.)

154. H. Y. Fang, ed., "New Horizons in Construction Materials," Vol. I, 1976, Envo Publishing Company, Lehigh Valley, PA.

155. "A. T. International: A Report," A. T. International, Washington, D.C., January, 1979. This is a report of AT International's first year.

156. Personal communications with K. Sacks, A. T. I., Omaha, Nebraska, October 24-7, 1979.

157. F. Smith, ed., "The Relevance of AT Developments in the U.S. to the Third World: A Compendium of U.S. AT Organizations," TRANET, Box 567, Rangeley, Maine, Spring, 1979.

158. J. H. Ashworth, "Renewable Energy Sources for the World's Poor: A Review of Current International Development Assistance Programs," Draft Report, SERI, Golden, Colorado, April, 1979. Published as SERI Report TR-195. Cited in Reference 19 at 1-39.

159. The author's four years as a Peace Corps Volunteer (PCV), working on rural development planning and construction, contained a number of instances of fellow PCV involvement in rural handicrafts, businesses, or construction, many of which were hampered by a lack of support or technical skills or contacts.

160. Reconnection, Vol. II, No. 1 (May, 1979), p. 9.

161. Many of VITA's requests from developing countries came from PCVs or local citizens who have been told of VITA by PCVs.

162. AID, "Summary of Agency for International Development Science and Technology Activities," 6 July, 1979.

163. "International Development Cooperation Act of 1979," Title IV (22 USC 3501-3513), Public Law 96-53, 93 STAT. 371 et seq.

164. IFTC/Planning Office, "Institute for Technological Cooperation, Summary Report," March 1, 1979; see also "Institute for Technological Cooperation: Why a Semi-Autonomous Institute?," Author unknown, undated.

165. John Walsh, "New Institute Passes First Test in Congress," Science, Vol. 204 (27 April, 1979), pp. 385-7.

166. Multiple addressee memorandum from James T. McIntyre, Jr., Director, U.S. Office of Management and Budget, entitled "Presidential Decisions on Foreign Assistance Organization," dated 15 February, 1979.

167. Congressional Record-Senate, October 11, 1979, pp. S14364-S-14366.

168. Thomas Kaithayil, "'Imperialism's' Top Secret Technology," Asiaweek, Vol. 5, No. 47 (30 November, 1979), pp. 25-6.

169. P. L. De and A. C. Banerjee, eds., "Building Research in India: Proceedings of Silver Jubilee Congress of CBRI," CBRI, Roorkee, 1973.

170. J. P. R. Falconer, "A Building System for Ghanian Housing," Seventh Annual AIA Research Conference, Cincinnatti, Ohio, November 3, 1970.

171. "Report of the United Nations Conference on Technical Co-operation Among Developing Countries," held in Buenos Aires, 30 August to 12 September, 1978, UN, New York, 1978 (E. 78. II. A.11).

172. ESCAP Newsletter, No. 1 of 1978, UN Economic and Social Commission for Asia and the Pacific, 1978, p. 19.

173. Personal communication from P. Johnston, Central Planning Office, Fiji, to the author, 4 December, 1978.

174. Reconnection, Vol. 1, No. 5 (March, 1979), p. 17.

175. Report by Willem Riedijk, Head, Science, Technology and Society Section of Delft University, The Netherlands, to ATRRU Study Team, 13 November, 1978.

176. Willem Riedijk, editor, Appropriate Technology for Developing Countries, Delft University Press, The Netherlands, 1979.

177. John Paxton, editor, The Statesman's Yearbook, 1978-1979, 115th edition, St. Martin's Press, New York, 1978.

178. From author's personal notes. RILEM is headquartered at: 12 Rue Brancion, 75 737 Paris Cedex 15, FRANCE.

179. Harold M. Draper, III, "Unexploited Plants of the American Deserts -- Guayule and Jojoba," Washington University, April, 1979. Published as CDT Report Number 79/2, August, 1979, under the title "Unexploited Desert Plants: Guayule and Jojoba."

180. Columnist Jack Anderson's columns on AID during 1977 and 1978 are examples.

181. Thomas R. Odhiambo, "How to Bridge the Scientific Gap," Bulletin of the Atomic Scientists, Vol. 35, No. 6 (June, 1979), pp. 35-8.

182. Albert Fishlow, Carlos F. Diaz-Alejandro, Richard R. Fagan, and Roger D. Hanson, Rich and Poor Nations in the World Economy, McGraw-Hill, New York, 1978.

183. Miguel S. Wionczek, "The NIEO: A Diagnosis of the Past Failures and the Prospects for the Future," paper presented at the Meeting on Progress in the Establishment of a New International Economic Order: Obstacles and Opportunities, Mexico City, E.U.M., 8-13 January, 1979.

184. U.S. Congress, "Foreign Assistance Act of 1966," 89th Congress, 2nd Session. Cited in reference 27 at p. 9.

185. S. Pruthi and P. S. Nagpaul, "Pattern and Role of Informal Communications in R&D," CSIR Monograph/Report Series, No. 1 of 1978, CSIR, New Delhi, 1978.

186. Julius K. Nyerere, "A Trade Union for the Poor," Bulletin of the Atomic Scientists, Vol. 35, No. 6 (June, 1979), pp. 38-9.

187. N. R. Hill, "Opportunities for Technical Cooperation Between Developing Countries for Producing Building Materials," background paper for Working Group No. 5, Appropriate Technology for the Production of Cement and Building Materials, at UNIDO's International Forum on Appropriate Industrial Technology, New Delhi/Anand, India, 20-30 November, 1978. (ID/WG.282/49).

9. VITA

1) Born 1 September, 1948.

2) Attended the Ohio State University from October, 1966, to June, 1970. Received the degree of Bachelor of Science in Architecture in June, 1970.

3) Served as Peace Corps Volunteer, working as Minor Works Advisor in Fiji from January, 1971 to August, 1974. Significant portion of this position involved the development of designs and supervision of projects which utilized local skills and materials.

4) Attended Washington University from August, 1978, to the present date. Participated in Center for Development Technology research program in Appropriate Technology for Renewable Resource Utilization in the academic year 1978-9; awarded Graduate Research Assistantship in June, 1979.

May, 1980